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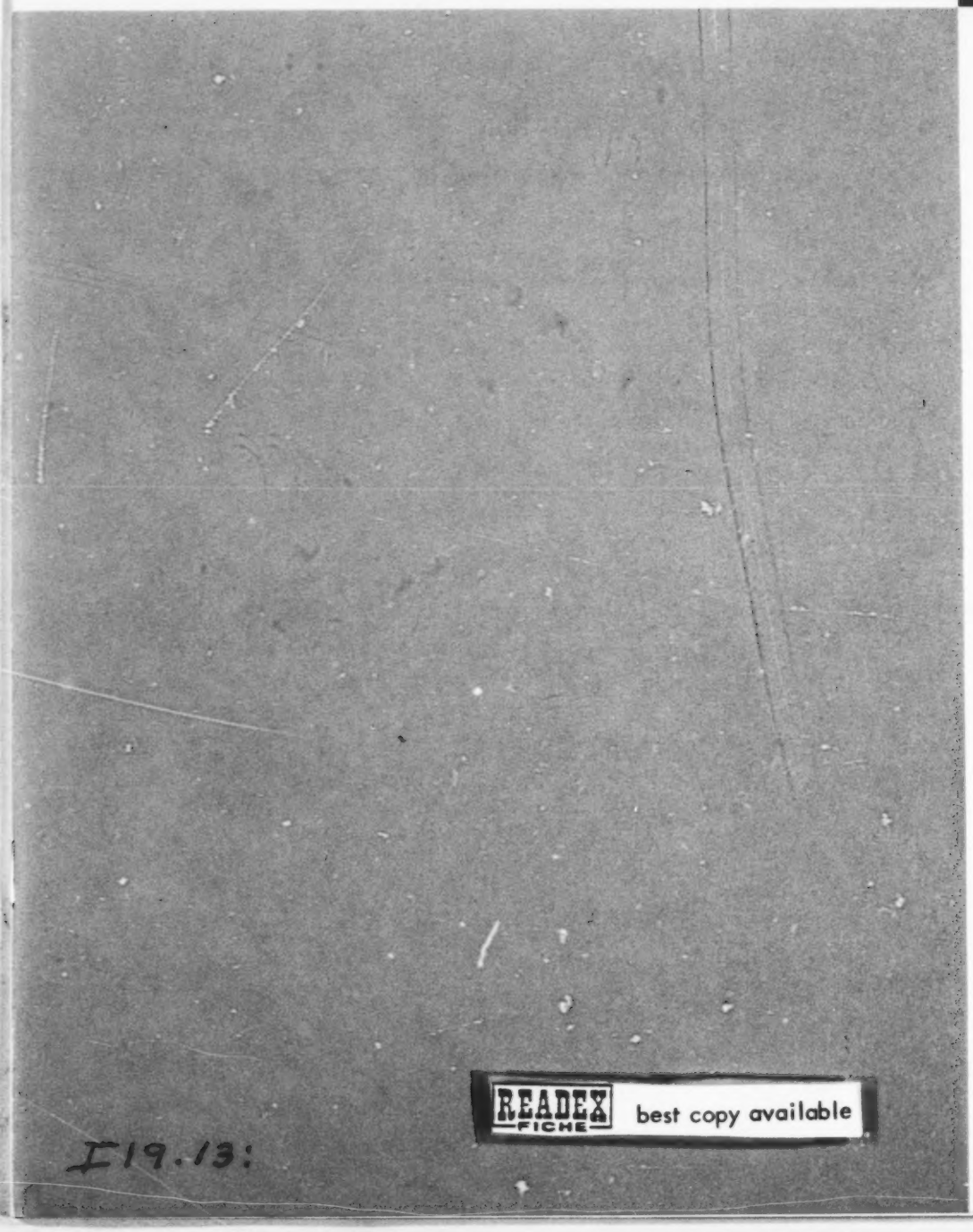
Sources of Coal-Mine Drainage and Their Effects on Surface-Water Chemistry in The Claybank Creek Basin and Vicinity, North-Central Missouri, 1983–84



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Prepared in cooperation with Missouri Department of Natural Resources, Land Reclamation Commission and U.S. Department of the Interior Office of Surface Mining Reclamation and Enforcement

Sources of Coal-Mine Drainage and Their Effects on Surface-Water Chemistry in The Claybank Creek Basin and Vicinity, North-Central Missouri, 1983–84

By DALE W. BLEVINS

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Misssouri Department of Natural Resources,
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Conversion Factors

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	*By*	*To obtain metric (SI) unit*
acre	0.4047	hectare
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter (mm)
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
pound (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 9/5\ °C + 32.$$

The value of a metric unit is decreased by a factor of 1,000,000 by the prefix micro (μ), 1,000 by the prefix milli (m), and 100 by the prefix centi (c). It is increased by a factor of 1,000 by prefix kilo (k).

Sources of Coal-Mine Drainage and Their Effects on Surface-Water Chemistry in The Claybank Creek Basin and Vicinity, North-Central Missouri, 1983–84

By Dale W. Blevins

Abstract

Eighteen sources of drainage related to past coal-mining activity were identified in the Claybank Creek, Missouri, study area, and eight of them were considered large enough to have detectable effects on receiving streams. However, only three sources (two coal-waste sites and one spring draining an underground mine) significantly affected the chemistry of water in receiving streams.

Coal wastes in the Claybank Creek basin contributed large quantities of acid drainage to receiving streams during storm runoff. The pH of coal-waste runoff ranged from 2.1 to 2.8. At these small pH values, concentrations of some dissolved metals and dissolved sulfate were a few to several hundred times larger than Federal and State water-quality standards established for these constituents. Effects of acid storm runoff were detected near the mouth of North Fork Claybank Creek where the pH during a small storm was 3.9.

Coal wastes in the streambeds and seepage from coal wastes also had significant effects on receiving streams during base flows. The receiving waters had pH values between 2.8 and 3.5, and concentrations of some dissolved metals and dissolved sulfate were a few to several hundred times larger than Federal and State water-quality standards.

Most underground mines in the North Fork Claybank Creek basin seem to be hydraulically connected, and about 80 percent of their discharge surfaced at one site. Drainage from the underground mines contributed most of the dissolved constituents in North Fork Claybank Creek during dry weather. Underground-mine water always had a pH near 5.9 and was well-buffered. It had a dissolved-sulfate concentration of about 2,400 milligrams per liter, dissolved-manganese concentrations ranging from 4.0 to 5.3 milligrams per liter, and large concentrations of ferrous iron. Iron was in the ferrous state because of reducing conditions in the mines. When underground-mine drainage reached the ground surface, the ferrous iron was oxidized and precipitated to form large, orange deposits of ferric hydroxide around the site and in streambeds.

Generally, drainage from strip mines had dissolved-sulfate concentrations several times larger than drainage from unmined areas. However, effects of drainage from strip mines on receiving streams were minimal when compared to the drainage from coal wastes and underground mines.

No appreciable effects of mine-related drainage were detected in the water of the Claybank Creek arm of Thomas Hill Reservoir at the time of sampling because beaver bogs upstream had trapped suspended coal wastes and moderated the effects. However, the concentration of coal in the bottom material was 60 percent of the coal concentration in coal wastes at Keota, indicating that the reservoir had received these wastes during the past.

INTRODUCTION

Coal mines opened in the Claybank Creek basin of Macon County, Missouri (fig. 1), as early as 1860 (Taylor and Co., 1910) and produced the largest quantities of coal from 1880 to 1920. From 1899 to 1910 and during several previous years, Macon County was the largest coal-producing county in Missouri, and the underground mines in the Claybank Creek study area were the most significant coal-producing field in the State (Hinds, 1912). The location of these mines and strip mines that were developed later in the Claybank Creek study area are shown in figure 2.

Problems and Objectives

The visual effects of mine-related drainage in the Claybank Creek basin have been obvious to even casual observers for many years (fig. 3). Consequently, a significant quantity of data has been collected by other organizations and individuals. These data are presented or summarized in the tables 17, 18, and 19 at the back of this report. However, many of the sources of mine-related drainage had never been individually related to

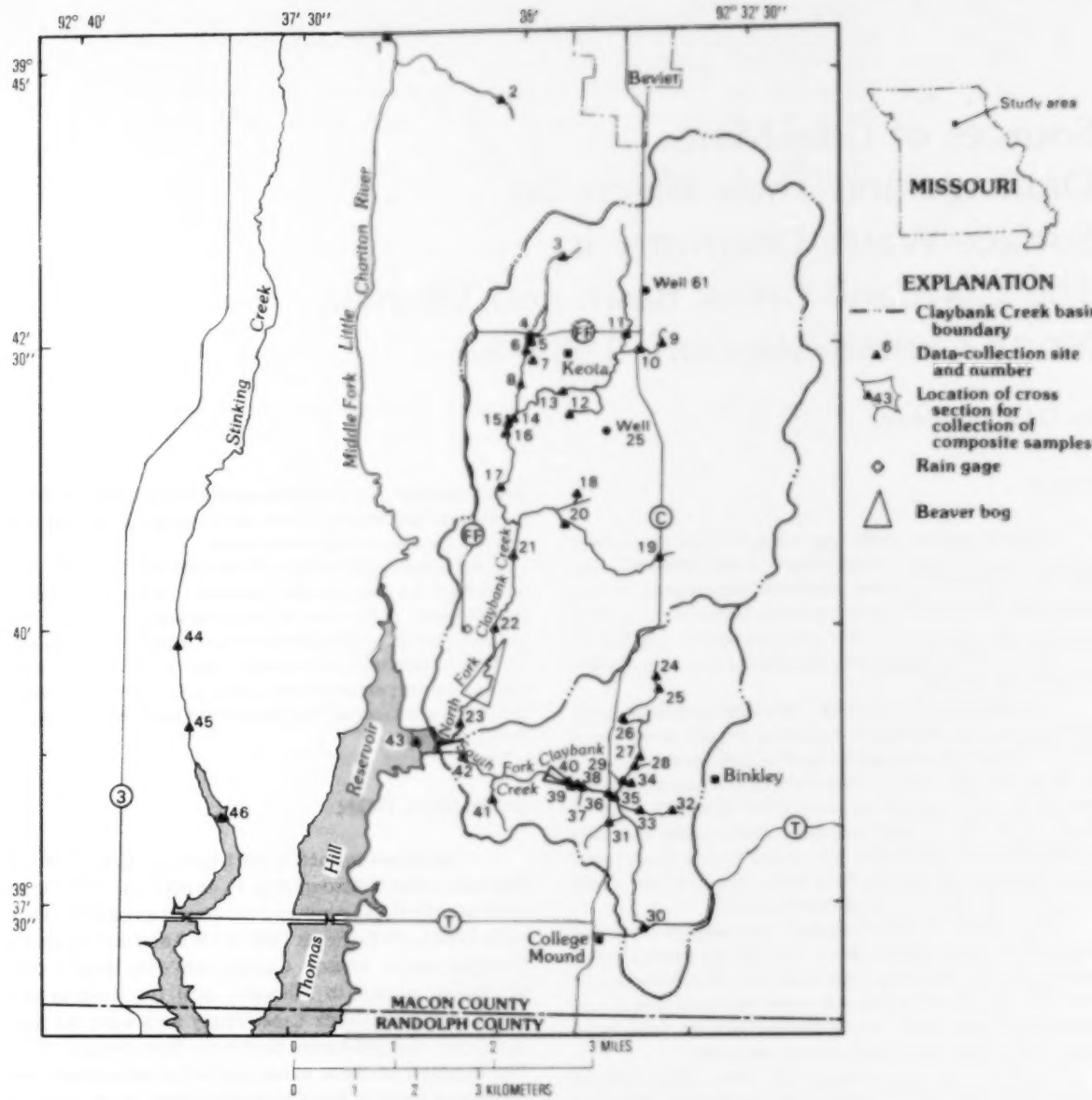


Figure 1. Location of study area, Claybank Creek basin, and data-collection sites.

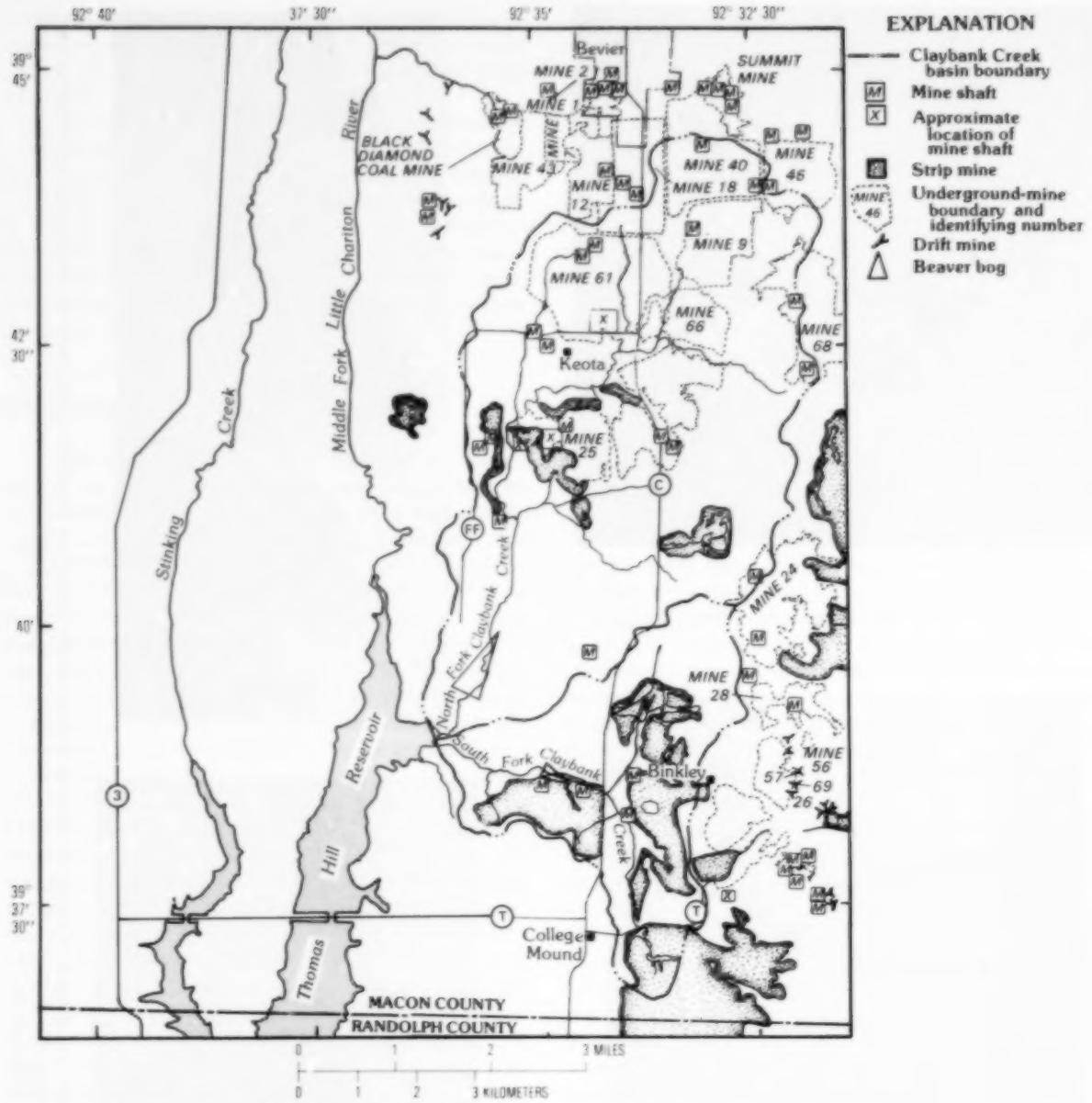


Figure 2. Location of past coal-mining activites in the Claybank Creek basin.

Figure 3. Appearance of selected sources and streams receiving mine-related drainage in the North Fork Claybank Creek basin. *A*, underground-mine drainage and iron deposit at site 14; *B*, tributary receiving underground-mine drainage; *C*, iron deposits on streambank where underground-mine drainage from 18 enters receiving stream; *D*, erosion of coal wastes near Keota (site 6).

specific mining disturbances, the water chemistry of many sources was unknown, and the relative effects of each source on the chemistry of receiving waters were unknown.

To provide the data necessary for selection of reclamation sites by the State, the U.S. Geological Survey in cooperation with the Missouri Department of Natural Resources, Land Reclamation Commission, made a study to identify all sources of mine-related drainage and to determine the relative effects of each source on water chemistry in the receiving streams in the Claybank Creek basin and in Thomas Hill Reservoir. This report presents the results of that study.

Description of Study Area

The Claybank Creek study area, which includes part of the Stinking Creek basin, consists of about 80 mi^2 (square miles) in the north-central coal-mining region of Missouri (fig. 1). The area is mantled with glacial drift that is as much as 100 ft (feet) thick on the drainage divides in the northeast part of the area. However, in places, the drift has been removed by erosion (Central Coal and Coke Mining Co., Kansas City, Mo., drill records, written commun., 1983). The bedrock consists of clay, shale, sandstone, coal, and occasionally, limestone (fig. 4). Significant Pennsylvanian bedrock formations in the study area in order of increasing age include the Lagonda, Bevier, and Verdigris Formations (Gordon, 1896, p. 19–21; Koenig, 1961, p. 88). The Lagonda Formation lies on top of the Bevier-Wheeler coal seam, and ranges from 18 to 50 ft thick. Its lithology changes considerably in short-vertical and horizontal distances, but usually is one of the following: sandstone, sandy shale, shale, or a blue clay (Gordon, 1896; Central Coal and Coke Mining Co., Kansas City, Mo., drill records, written commun., 1983). Blue or gray clay overlies the Bevier-Wheeler coal in the four holes drilled during this study. The Bevier-Wheeler coal is 3 to 5 ft thick. This coal is the most significant seam in the Claybank Creek study area, and about 14 mi^2 have been affected by underground mining (fig. 2). The Bevier and Wheeler coal seams are separated by only 2 to 3 in. (inches) of parting in the Claybank Creek basin and are, therefore, generally discussed as a single unit. Some 6 to 18 in. of underclay in the Verdigris Formation form the base of the Bevier-Wheeler Coal and the floor of underground mines. Just below the underclay are several feet of the Ardmore Limestone. The bottom part of the Verdigris and formations immediately below it primarily consist of 25 to 30 ft of shale, sometimes sandy, with a few thin beds of limestone.

From a regional perspective, the strata dip slightly to the northwest. However, two local structures, the College Mound-Bucklin anticline and the Macon-Sullivan trough cause coal seams to be deeper in the northeastern part of the study area. A structure-contour map (fig. 5) drawn on the base of the Roubidoux Formation, which is several hundred feet below the coal seams, shows the general shape and size of these structures.

The predominant land uses in the Claybank Creek study area are pasture and row crops. Abandoned surface mines occupy 0.6 mi^2 (3.7 percent) of the North Fork Claybank Creek basin and 2.0 mi^2 (18 percent) of the South Fork Claybank Creek basin (fig. 2). Both forks of Claybank Creek discharge into Thomas Hill Reservoir (fig. 1). Coal primarily was extracted by surface mining from the Bevier-Wheeler coal seam between 1950 and 1978. No mining of any kind presently (1984) is occurring in the study area. More than 30 strip pits are associated with the surface mines.

Methodology

Reconnaissance measurements of discharge, specific conductance, and pH were made at many sites during early summer 1983 to locate the sources of mine drainage, to develop conceptual models of the hydrology in the Claybank Creek basin, and to help design the sampling network shown in figure 1. After the reconnaissance data were collected, sites 6 and 18 were selected for continuous monitoring of discharge, specific conductance, and pH because of major effects on receiving streams from these sources and unknown responses to variation in flow regimes.

The sampling network was designed to obtain detailed chemical and discharge data on significant sources of mine drainage, on the receiving streams, and on drainage from unmined basins, such as Stinking Creek, for comparison. All sites in this network were sampled and measured during high base-flow and low base-flow conditions. High base flow is defined in this report as streamflow that contains no storm runoff, but occurs soon after the storm ends, and low base flow is defined as streamflow that is sustained by ground-water outflow after several weeks of relatively dry weather. Low base-flow sampling was done September 21–23, 1983. A U.S. Geological Survey rain gage located near the center of the study area (fig. 1) showed that 0.49 in. of rain had fallen during the 3 days before September 21, and 1.41 in. of rain had fallen during the previous 7 days. However, only 2.50 in. had fallen since September 1, and this was the first precipitation that occurred after an unusually hot, dry summer. Thus, most of both forks of Claybank Creek were dry during the sampling period. High base-flow sampling was done April 18–20, 1984. No rain had fallen during the 3 days before April 18. During the previous 7 days, 0.47 in. of rain had fallen and 4.60 in. of rain had fallen since April 1.

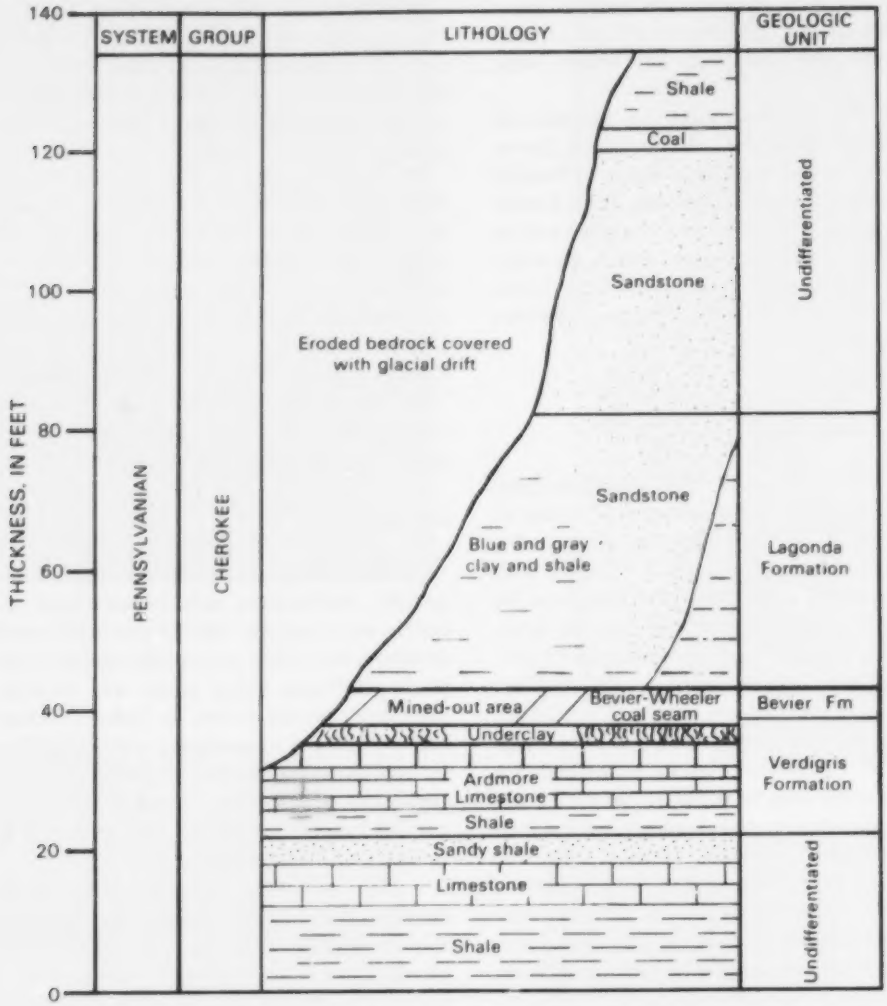
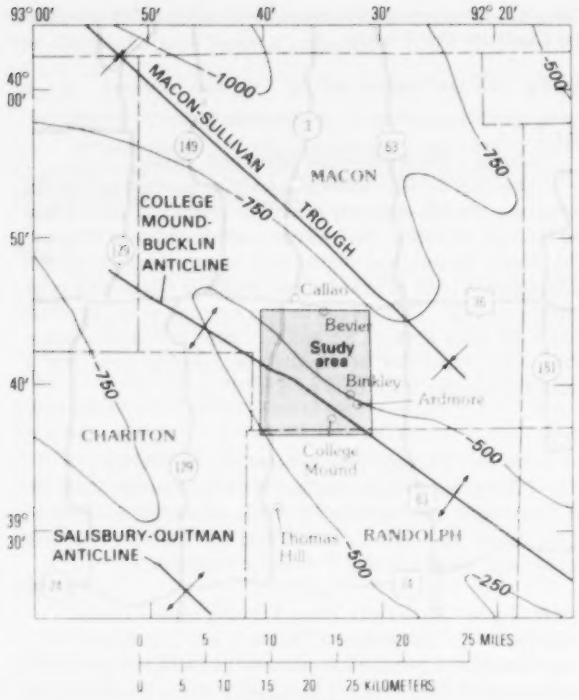


Figure 4. Generalized thickness and lithology of geologic formations (modified from Koenig, 1961).

Various constituent loads emanating from mine-drainage sources were used to determine the relative significance of each source, and constituent loads in receiving streams were used to determine the relative effects of mine-drainage sources during base flows. Concentrations of various constituents in samples from the Claybank Creek basin were compared to concentrations in samples collected at the same time in nearby basins unaffected by mining (for example, Stinking Creek) to determine the effects of mine drainage in the Claybank Creek basin.

Samples of runoff were collected from the Claybank and Stinking Creek basins and one source of mine drainage to determine the effects of mine drainage on the water chemistry of receiving streams during storm runoff. Samples were collected during the storms of August 30, 1983 (1.61 in. of rain); October 19, 1983 (0.94 in.); October 21, 1983 (1.38 in.); November 19–20, 1983 (0.53 in.); April 12–13, 1984 (0.27 in.); and April 21–23, 1984 (1.23 inches).

Bottom-material samples were collected from several sites in the sampling network to determine if or how far downstream coal wastes were being deposited in the stream bottom. Water and bottom-material samples were collected from the Claybank Creek arm of Thomas Hill Reservoir (affected by mining) and from the Stinking Creek arm of Thomas Hill Reservoir (not affected by mining) to determine effects of mine drainage on the reservoir. Two wells were drilled into underground mines to collect samples of mine water to determine the



EXPLANATION

—250— **Structure Contour**—Shows altitude of base of the Roubidoux Formation, which is several hundred feet below the Verdigris Formation. Contour interval 250 feet. Datum is sea level

Figure 5. Rock structure in and adjacent to the study area (modified from McCracken, 1971).

chemical character and water level in the underground mines.

Laboratory analyses of water samples for all properties and constituents used in this study, except suspended sediment, were made by the U.S. Geological Survey laboratory in Arvada, Colo., in accordance with procedures outlined by Skougstad and others (1979). Their procedures also were used in collecting samples for these properties and constituents. Where flow was sufficient, depth-integrated water samples were collected at several locations in the stream cross section by lowering bottles to the bottom and raising them to the surface at a constant rate (equal-width-increment method). These samples were composited to represent the entire stream cross section. Low-flow samples were collected from a single vertical traverse near the midpoint of the cross section. Suspended-sediment samples were collected according to procedures outlined by Guy (1969) and Guy and Norman (1970) and were analyzed in the U.S. Geological Survey laboratory, Rolla, Mo.

Bottom-material samples were collected by scooping material from the upper 2 in. of the stream bottom at several locations in the cross section. The bottom material was sampled in reaches with moderate velocities and samples were analyzed in accordance with procedures outlined by Skougstad and others (1979).

Before sample collection, wells penetrating the underground mines were pumped for several minutes until the water extracted reached a constant specific conductance and water temperature and all water in the well bore was removed. Wells were cased with 4-in. diameter, polyvinyl chloride pipe.

Dissolved constituents were determined in water samples that were filtered at the time of sampling through a 0.45-micrometer membrane in a polyvinyl chloride chamber using a peristaltic pump as the pressure source. Total chemical constituents were determined from unfiltered samples and included quantities recovered from suspended sediment or bottom material by soft-digestion procedures. Water samples analyzed for metals were acidified in the field with double-distilled analytical-grade nitric acid to a pH value of less than 3. Water temperature was measured with a mercury thermometer to the nearest 0.5 °C (Celsius). Specific conductance was measured using a portable conductivity meter with temperature compensation designed to express readings in μS/cm (microsiemens per centimeter) at 25 °C. The potentiometric method was used to measure both pH and alkalinity.

Acidity is defined in this report as the capacity of a solution to react with hydroxyl ions and is determined by titration to a pH of 8.3. Alkalinity is similarly defined, with the word "hydrogen" substituted for hydroxyl, and titrations are done to a pH of 4.5.

Acknowledgments

Residents and landowners in the study area were helpful in supplying information about their wells, allowing water-level measurements to be made, and allowing access to their property for sampling, well drilling, and other data-collection activities. Appreciation also is extended to the Central Coal and Coke Mining Co., Kansas City, Mo., for allowing access to their mine maps and drill records.

The Process of Acid Formation in Coal-Mine Drainage

The formation of sulfuric acid in mine waters is caused by the oxidation of iron disulfide (FeS_2) minerals, primarily pyrite and marcasite, by either oxygen (O_2) or ferric iron (Fe^{+3}). According to Sato (1960) and Nordstrom (1982), the initial oxidation of pyrite is described by the following equation:

$$FeS_2 + O_2 + 2H^+ \rightarrow Fe^{+2} + S_2^0 + H_2O_2 \qquad (1)$$

Although equation 1 actually consumes hydrogen ions, the further oxidation of its products causes a net increase in hydrogen ions according to:

$$Fe^{+2} + 5/2H_2O + 1/4O_2 \rightarrow Fe(OH)_3 + 2H^+ \quad (2)$$

and

$$S^0_2 + 3O_2 + 2H_2O \rightarrow 2SO_4^{-2} + 4H^+. \quad (3)$$

The required ingredients for this process include oxygen and acid; however, pyrite can also be oxidized by ferric iron in the absence of oxygen (Garrels and Thompson, 1960) according to:

$$FeS_2 + 14Fe^{+3} + 8H_2O \rightarrow 15Fe^{+2} + 2SO_4^{-2} + 16\ H^+. \quad (4)$$

Although this equation does not require oxygen directly, it does require large concentrations of dissolved ferric iron. Ferric iron can be present only when the pH is less than 4.5 and when ferric iron is being rapidly replenished by the aerobic bacteria *Thiobacillus ferrooxidans* according to equation 2. Therefore, oxygen is still indirectly required for equation 4. According to Singer and Stumm (1970), the rate of pyrite oxidation is much faster for equation 4 than for equation 1 at pH values below 4.0 and in the presence of *Thiobacillus ferrooxidans*. Singer and Stumm also concluded that the oxidation of iron often was the rate-limiting step in the production of acidic mine drainage.

The acid water can dissolve other constituents including metals, such as aluminum, manganese, and zinc. However, acid mine drainage commonly is neutralized by carbonate rocks or neutral-to-alkaline receiving streams, and most metals (with the major exception of manganese) precipitate out of solution. Neutralization does not change the concentration of sulfate (Toler, 1980); thus, sulfate is the best indicator of mine drainage.

IDENTIFICATION OF SOURCES OF MINE-RELATED DRAINAGE

During a field reconnaissance of the study area in the early summer of 1983, the following criteria were used to help locate sources of mine-related drainage:

1. Specific-conductance values greater than 1,000 μS/cm at 25 °C (indicator of large sulfate concentrations).
2. Values of pH less than 6.0.
3. Red or orange staining of ground or streambed (indicator of large iron concentrations).

These criteria are based on those used by the U.S. Department of the Interior (1968).

Using these criteria, 18 sources of mine-related drainage were determined. These sources are listed with a narrative description of each one in table 1. Of the 18,

Table 1.—Description of sources of mine-related drainage in the Claybank Creek basin

[See fig. 1 for site locations and fig. 2 for mine locations]

Site 2

Source - Black Diamond Mine near Bevier

Drainage from an underground mine emerged as a spring at the base of a hill. An easily detectable quantity of gas bubbled out through the spring. No hydrogen sulfide odor was detected. The stream bottom was coated with large quantities of iron precipitates. A resident reported that discharge was much greater during past years. This site can be characterized as having water with a pH value between 5.5 and 6.0, large sulfate concentrations, large quantities of rapidly precipitating iron, and a discharge ranging from 0.05 to 0.10 ft^3/s.

Site 3

Source - Tailings piles at Mine 61 near Bevier

During wet weather, tailings piles near the old shaft entrance to underground Mine 61 produced a small quantity of acidic water that was neutralized either before or by the slackwasher pond about 0.75 mile downstream.

Site 6

Source - Coal wastes at Keota

Two slurry ponds (fine coal wastes) and two gob piles (coarse coal wastes) were left by a coal-washing facility and an underground mine at Keota. Dams holding the slurry have been breached allowing coal wastes to wash into a tributary of North Fork Claybank Creek during runoff. Both runoff and seepage from these wastes had pH values between 2.1 and 2.8 and large concentrations of dissolved sulfate and metals. Rain water immediately became acidic when it contacted the coal wastes. Runoff contained suspended-sediment concentrations much larger than those at sites unaffected by mining.

Site 7

Source - Underground mine near Keota

A small, red spring that flows only during wet weather is near a passage of a small underground mine near Keota. The grass was stained red in a small area around the spring.

Site 12

Source - Northern part of underground Mine 25 near Keota

A small, wet-weather seep existed near the original entrance slope to an underground mine. A long-time resident reported that discharge was much greater at this site before the mine was opened by a strip-mine operation at site 18.

Site 14

Source - Northwest part of underground Mine 25 near Keota

A small spring emanating from an underground mine at the base of a hill within 50 ft (feet) of North Fork Claybank Creek was marked by a large deposit of iron precipitates covering almost an acre and as much as 5 ft deep. Several mine-collapse features were nearby. Water from this site had characteristics similar to those of other underground mine discharges (sites 2 and 18) and had a fairly constant discharge of about 0.05 ft^3/s.

Table 1.—Description of sources of mine-related drainage in the Claybank Creek basin—Continued

Site 16

Source - Underground mine or, possibly, an old strip mine

A small quantity of water emanating from a spring close to an old underground drift mine and a small strip mine stained the ground red in a small area.

Site 18

Source - Southern part of underground Mine 25 near Keota

An old passage of underground Mine 25 was opened by a small strip mine during the 1950's, allowing drainage from Mine 25 at this site. The stream bottom was coated with large quantities of iron precipitates and the water was bright orange. Drainage was into the last-cut lake of the strip mine that overflowed into a tributary of North Fork Claybank Creek. This was the largest source of mine drainage into Claybank Creek during dry weather. It can be characterized the same as site 2, except the discharge was between 0.35 and 0.85 ft^3/s.

Site 19

Source - Strip pits at County Highway C near Binkley

Several strip pits produced water during high base-flow conditions with sulfate and metals concentrations that were similar to those at background sites. The discharge during high base flow was 0.83 ft^3/s.

Site 25

Source - Big strip pit near Binkley

A large, deep lake produced water with sulfate concentrations larger than background concentrations, but only slightly more than the U.S. Environmental Protection Agency (1976) standard for drinking water (500 milligrams per liter). Base-flow discharge was about 0.10 ft^3/s.

Site 28

Source - Coal-waste ponds near Binkley

Acidic water seeped from the base of the earthen dam of a large coal-waste pond. Other wet-weather seeps emanated from the base of several other earthen dams and breached dikes used to contain some small coal-waste ponds just upstream from the large pond. Water from this site had a pH value less than 3.0 and large concentrations of dissolved sulfate and metals. The discharge ranged from 0 to 0.22 ft^3/s during base flow.

Site 30

Source - Strip pit at County Highway T near College Mound

This pit produced water with sulfate concentrations larger than those at background sites, but only slightly larger than the U.S. Environmental Protection Agency (1976) standard for drinking water. The discharge during high base flow was 1.1 ft^3/s.

Site 31

Source - Strip pits at County Highway C near College Mound

The outflow from two pits combined to produce water with specific-conductance values more than twice the values at background sites. However, discharge was only 0.08 ft^3/s at high base flow.

Site 32

Source - Acid strip pit near Binkley

This large pit produced acidic water caused by coal wastes in one end of the pit. Values of pH were less than 3.5 and concentrations of dissolved sulfate and metals were large. Discharge was 0.13 ft^3/s during high base flow. Outflows commonly were neutralized with treatments of sodium hydroxide.

Site 34

Source - Strip pit near coal-waste pond near Binkley

This pond may be acidified by water seeping from the large coal-waste pond just above and adjacent to it. Discharge was less than 0.01 ft^3/s at high base flow.

Site 37

Source - Strip pit near College Mound

This pit produced water with dissolved-sulfate concentrations several times larger than those at background sites and three times larger than the U.S. Environmental Protection Agency (1976) standard for drinking water. Discharge during high base flow was 0.13 ft^3/s.

Site 38

Source - Unnamed underground mine near South Fork Claybank Creek

Small, bright-red seepage probably eminated from a small underground mine near the south side of South Fork Claybank Creek. The water was neutral, but had a large specific-conductance value. The discharge was less than 0.01 ft^3/s, even at high base flow, and did not reach the creek.

Site 41

Source - Strip-pit outflow near the mouth of South Fork Claybank Creek

This pit produced water with larger specific-conductance values than at background sites. Discharge was 0.14 ft^3/s during high base flow.

8 were considered large enough to have detectable effects on the pH values or sulfate concentrations in receiving streams. However, only three drainage sources caused major effects on receiving streams. These sites were drainage from the southern part of underground Mine 25 near Keota (site 18), coal wastes near Keota (site 6), and coal-waste ponds near Binkley (site 28).

Underground Mines

Underground mines ranging in depth from 30 to 180 ft below the land surface underlie about 14 mi^2 of the study area. Collapse features appear where the overlying rock is thinnest. Mining was done using the

room-and-pillar method, leaving 20 to 40 percent of the coal as pillars that supported the roof.

Flow System

Nearly all drainage from the system of abandoned underground coal mines in the North Fork Claybank Creek basin surfaces at three locations: sites 2, 14, and 18 (fig. 1, table 1). Two of these sources (sites 14 and 18) emanate from Mine 25, which is at the southern end of the mine system, and the other underground mine source (site 2) is the Black Diamond Mine at the north end of the mine system, just outside the Claybank Creek basin. Wells penetrating Mine 25 and Mine 61 (fig. 1) were drilled and logged to obtain water-quality and water-level data.

Two sets of synoptic discharge measurements indicate that about 80 percent of the underground-mine drainage in the study area originates at site 18. The discharge at this site was continuously monitored from October 7 to December 22, 1983, and from March 15 to June 13, 1984 (fig. 6). Mine water discharge at this site ranged from 0.50 to 0.85 ft^3/s during these periods, and a discharge measurement made during low base flow was only 0.37 ft^3/s (table 2). These data indicate the consistency of discharge from the mines with small fluctuations related to seasonal precipitation. The persistence of discharge, mine maps from Central Coal and Coke Mining Co., and statements from residents who had worked in the mines indicate that most of the mines shown in the North Fork Claybank Creek basin (fig. 2) are hydraulically, if not physically, connected. Consequently, the entire area of underground mines in that basin will be referred to as an underground-mine system.

There is no evidence of drainage into the South Fork Claybank Creek from underground mines near the creek or of these mines being hydraulically connected to those in the North Fork Claybank Creek basin. Therefore, the underground mines in the South Fork Claybank Creek basin were not investigated further.

The impermeability of Pennsylvanian shale below the mines, relatively high position of the mine cavities, and large areal extent of the underground mines make downward percolation from the surface the most probable source for mine recharge. The relation between ground-water levels in the mines and seasonal precipitation, shown in figure 6, also indicates vertical recharge. Water levels measured in 25 privately owned wells completed in glacial drift averaged 5.81 ft below the ground surface and had a standard deviation of only 3.27 ft. These levels are several tens-of-feet higher than the levels measured in wells drilled into the underground mines and provide the necessary hydraulic head for downward percolation.

The general direction of flow in the underground-mine system is assumed to be from north to south because the major discharge points are located at the southern end of the system. However, flow through the underground-mine system is slow because of the small quantities of discharge compared to the volume (about 250,000 acre-ft) of the mines. The average replacement time for water in the mines probably is at least a decade.

Hydrochemistry

The largest source of underground-mine drainage in the study area (fig. 1, site 18) was continuously monitored for specific conductance and pH from October 7 to December 22, 1983, and from March 15 to June 13, 1984. The results indicated that the specific conductance generally ranged from 3,000 to 3,600 $\mu S/cm$ at 25 °C, and the pH ranged from 5.6 to 6.2. The minor fluctuations are indicative of the stable geochemical and hydrologic environments controlling the quality of water in the underground mines. The statistical summary of monthly samples collected by Kurt Piepenburg (University of Wisconsin, written commun., 1984, data summarized in table 19) the end of this report) indicates slightly smaller values of pH and specific conductance, but indicates the same general lack of variation at site 18.

Chemical data from water samples collected from two wells penetrating underground mines (fig. 1, wells 25 and 61) and three sites where underground-mine water emerges at the ground surface are presented in table 2. Excluding site 14, the chemical characteristics of the water from these sites are similar enough to indicate a common origin or similar geochemical environments. These characteristics include acidities between 74 and 646 mg/L (milligrams per liter) as calcium carbonate ($CaCO_3$) and alkalinities between 203 and 335 mg/L as $CaCO_3$, as well as concentrations of dissolved sulfate between 2,200 and 3,700 mg/L, dissolved ferrous iron between 120 and 270 mg/L, and dissolved manganese between 4.0 and 5.3 mg/L (Samples collected at site 14 had smaller alkalinity values and smaller concentrations of iron probably because the samples were collected some time after the water had emerged from the ground.) These values and concentrations are much larger than those measured in samples collected from the unmined Stinking Creek basin (table 2). However, concentrations of other dissolved metals were similar to or less than those measured in Stinking Creek. When compared with the chemistry of water in glacial drift, underground-mine water has smaller pH values by 1 to 2 pH units and much larger concentrations of dissolved sulfate, iron, and manganese (Gann and others, 1973).

The origin of a large part of sulfate in the underground mines may have been calcium sulfate in the

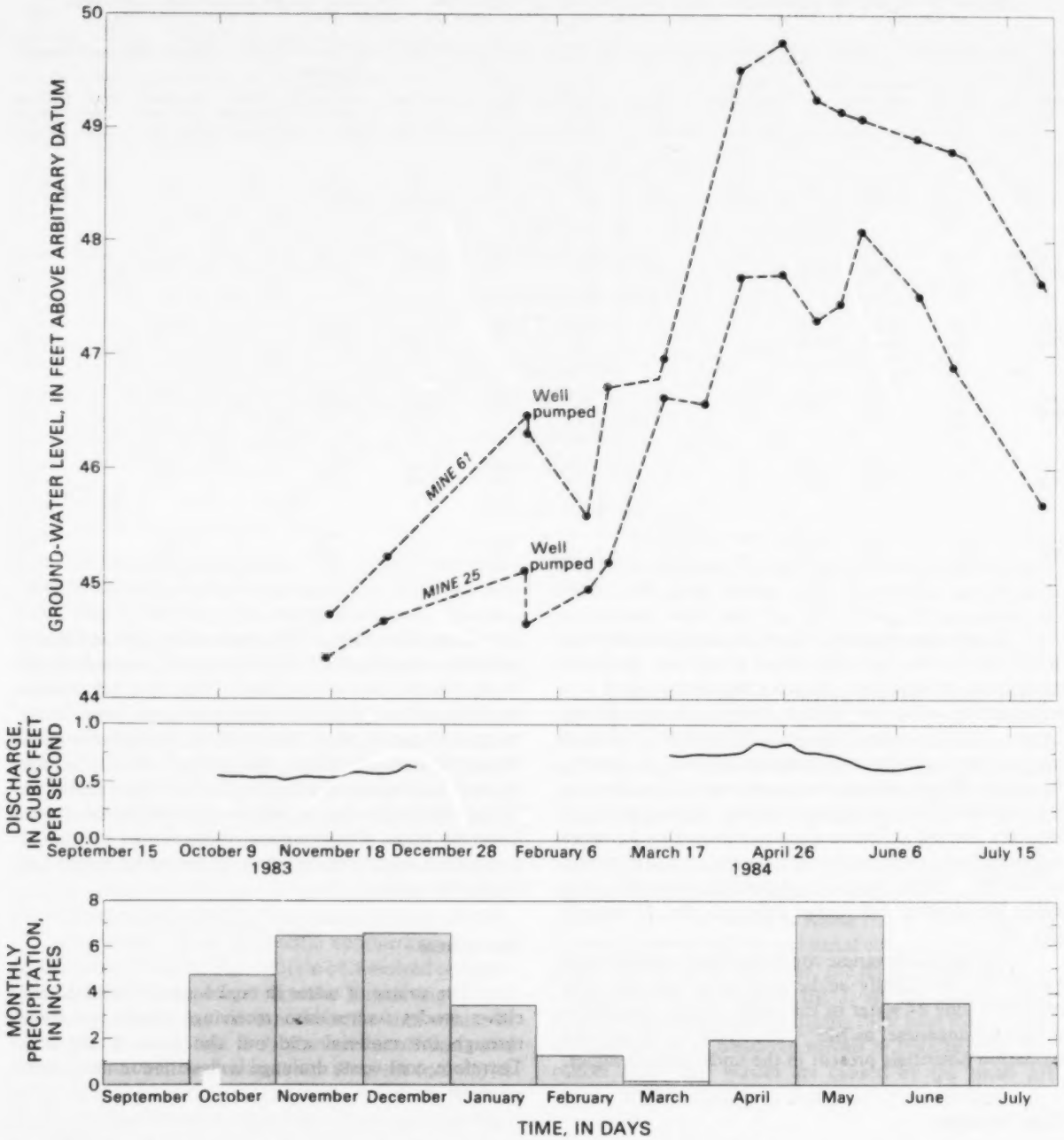


Figure 6. Plot of ground-water levels in underground mines, continuous discharge from Mine 25 at site 18, and monthly precipitation, 1983–84.

Bevier-Wheeler coal seam and rocks surrounding the mines. Gypsum ($CaSO_4 \cdot 2H_2O$) is common in sedimentary materials (Hem, 1970), and analyses of the Bevier-Wheeler coal from a location just 2 mi east of the study area contained 0.27 percent sulfate by weight (Wedge and others, 1976). However, dissolved-iron concentrations of 270 mg/L in Mine 61 indicate that at least part of the sulfate originated from the oxidation of iron disulfides.

Table 2. Analyses of water from underground mines and from Stinking Creek (unaffected by mining)

[Results in milligrams per liter, except as indicated. Sources can be located by site number in figure 1. Low base-flow samples were collected September 21-23, 1983, and high base-flow samples were collected April 18-20, 1984. ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; >, greater than; <, less than; --, no data]

Date or base-flow regime	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen	Acidity (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	Dissolved sulfate	Dissolved solids (residue at 180 °C)	Total aluminum	Dissolved aluminum	Total copper	Dissolved copper
						Well 25--Mine 25							
1-25-84	--	3,500	5.9	13.4	--	546	263	2,400	3,650	1.1	>0.1	0.009	<0.001
2-24-84	--	3,400	5.9	13.0	0.0	--	--	2,500	--	--	--	--	--
						Well 61--Mine 61							
1-26-84	--	4,800	5.9	14.0	--	646	335	3,500	5,340	.13	>0.1	0.004	>0.001
2-23-84	--	5,000	5.9	13.5	0.0	--	--	3,700	--	--	--	--	--
						Site 2--Black Diamond Mine							
Low	0.05	3,500	5.9	--	--	124	240	--	3,650	--	<0.1	--	<0.001
High	.09	3,500	5.7	--	--	94	203	2,400	3,680	--	.4	--	.002
						Site 14--Mine 25							
Low	0.07	3,500	5.8	--	--	50	180	2,400	3,330	--	<0.1	--	<0.001
High	.04	3,500	5.7	--	--	25	26	2,200	3,260	--	<.1	--	<.001
						Site 18--Mine 25							
Low	0.37	3,700	5.8	--	--	84	300	2,400	3,420	--	<0.1	--	<0.001
High	.54	3,400	5.6	--	--	74	242	2,400	3,330	--	<.1	--	<.001
						Site 44--Stinking Creek							
Low	0.01	850	8.2	--	--	0	260	130	429	--	<0.1	--	0.004
High	2.3	520	7.9	--	--	<5	126	130	337	--	<.1	--	.002

Large concentrations of iron in underground-mine water were at least partially caused by the near-zero concentrations of dissolved oxygen (dissolved oxygen was undetectable using the Winkler method (Skougstad and others, 1979) in water from wells 25 and 61). Without oxygen, iron is in the more soluble ferrous (+2) oxidation state. When underground-mine water is exposed to the atmosphere at the ground surface, large deposits of iron are formed as ferrous iron is oxidized to the more insoluble ferric (+3) oxidation state and iron precipitates as $Fe(OH)_3$. These deposits and precipitates in the water cause the striking red-orange color at sites 14 and 18 (fig. 3).

The large manganese concentrations probably were caused by the slightly acidic conditions and the long residence time of water in the mines. Large concentrations of manganese, as Mn^{+2}, are stable at the pH and oxidation potentials present in the underground mines.

Coal Wastes

Coal wastes in the Claybank Creek area are in three forms: gob piles, slurry ponds, and tailings from underground mines. All three coal wastes produced acidic water. Gob consists of coarse material that is separated from coal by shaking and washing and is left in large piles near the processing sites. Slurry is fine material washed from the coal and left to settle in ponds that are now abandoned (fig. 3*D*). A large part of the gob and slurry probably came from a 2- to 3-in. parting, separating the Bevier-Wheeler coal seam (Hinds, 1912), and they contain large quantities of pyritic shale and coal fines. Some crystals of pyrite more than 0.25 in. in diameter were observed in the gob piles at Keota (fig. 1, site 5). Tailings are material excavated from the shaft or slope entrances to underground mines as well as other excavated wastes from the mine. Consequently, these wastes consist of glacial-drift material mixed with, or buried by, pyritic and nonpyritic rocks.

Flow System

The source of water in coal wastes is rainfall that either erodes wastes into receiving streams or seeps through the material and out the base of the pile. Therefore, coal-waste drainage is classified in this report as either runoff or seepage.

Hydrochemistry

Both runoff and seepage from coal wastes generally can be characterized as having a pH value between 2.1 and 2.8, large acidities, and large concentrations of dissolved sulfate and metals when compared with streams unaffected by mining (figs. 7–9; table 3). Runoff had additional large quantities of coal-waste sediments and

Table 2. Analyses of water from underground mines and from Stinking Creek (unaffected by mining)—Continued

Date or base-flow regime	Discharge (ft^3/s)	Total iron	Dissolved iron	Total lead	Dissolved lead	Total manganese	Dissolved manganese	Total molybdenum	Dissolved molybdenum	Total zinc	Dissolved zinc	Total sulfide
						Well 25--Mine 25						
1-25-84	--	180	160	0.016	<0.001	4.8	4.4	<0.001	<0.001	0.05	0.05	--
2-24-84	--	180	170	--	--	--	--	--	--	--	--	2.3
						Well 61--Mine 61						
1-26-84	--	270	240	0.014	<0.001	5.5	5.3	<0.001	<0.001	0.05	0.07	--
2-23-84	--	270	270	--	--	--	--	--	--	--	--	<0.5
						Site 2--Black Diamond Mine						
Low	0.05	--	120	--	--	--	4.4	--	--	--	0.04	--
High	.09	--	140	--	--	--	4.3	--	--	--	.16	--
						Site 14--Mine 25						
Low	0.07	--	77	--	--	--	4.1	--	--	--	0.06	--
High	.04	--	23	--	--	--	4.0	--	--	--	.05	--
						Site 18--Mine 25						
Low	0.37	--	130	--	--	--	4.1	--	--	--	0.04	--
High	.54	--	140	--	--	--	4.0	--	--	--	.04	--
						Site 44--Stinking Creek						
Low	0.01	--	0.016	--	--	--	0.004	--	--	--	0.12	--
High	2.3	--	.016	--	--	--	.32	--	--	--	.18	--

metals in the suspended phase. The runoff from coal-waste sediments contained large quantities of copper and lead (table 3, site 8) in the suspended phase, whereas aluminum and manganese primarily remained in the dissolved phase. Zinc was evenly distributed between the suspended and dissolved phases.

Runoff sampled October 21, 1983, at North Fork Claybank Creek tributary (fig. 1, site 8) came from a small storm that caused little runoff from anywhere in the basin other than the coal wastes at Keota and, therefore, represents an undiluted worst case. During this storm, coal-waste sediments increased specific conductance and mean-storm concentrations of suspended sediment to values several times larger than those in runoff from the unmined Stinking Creek basin (table 4, site 44).

Decreased values of specific conductance during greater runoff indicate that dilution of dissolved constituents occurred during larger flows at a receiving-stream site (fig. 1, site 8) downstream from the coal wastes at Keota (fig. 1, site 6; figs. 7–9). Surface runoff and pond water from unmined areas upstream from the coal wastes at Keota dominated the water chemistry at site 8 after the initial runoff from the coal wastes had passed on May 20, 1984 (fig. 9).

The tendency of coal wastes to produce acidic water was illustrated by the following experiment: Two, 500-milliliter beakers were filled with (1) distilled water, and (2) with water having an alkalinity of 100 mg/L and near-neutral pH. About 100 grams of coal wastes were added to each beaker. The pH value decreased to 2.4 in both beakers as rapidly as the pH meter could respond. These data indicate that rainwater immediately becomes more acidic upon contact with the wastes, and the pH corresponds well with the pH of runoff measured in North Fork Claybank Creek tributary near Keota (fig. 1, site 8).

Chemical data from samples collected from sources of coal-waste seepage during high and low base flow are presented in table 5. Coal-waste seepage was more acidic and had larger concentrations of dissolved sulfate and metals than all other sources of mine drainage in the study area. Concentrations were much larger than at the unmined Stinking Creek site (table 5). Generally, the seepage had larger concentrations of dissolved constituents than the coal-waste runoff because of the lack of dilution. The seepage from coal wastes at Keota (fig. 1, site 6) had the largest dissolved-sulfate and metal concentrations determined in the study. However, the larger discharge from the coal-wastes at Binkley (fig. 1, site 28) caused larger loads of most constituents during high base flow. Large concentrations of dissolved metals in both seepage and runoff from coal wastes are caused by the small pH values, which allow even ferric iron to solubilize.

Spoil and Impoundments Associated with Surface Mining

Flow System

In surface mining, the soil, rocks, and glacial drift above the coal are excavated and left in long piles called

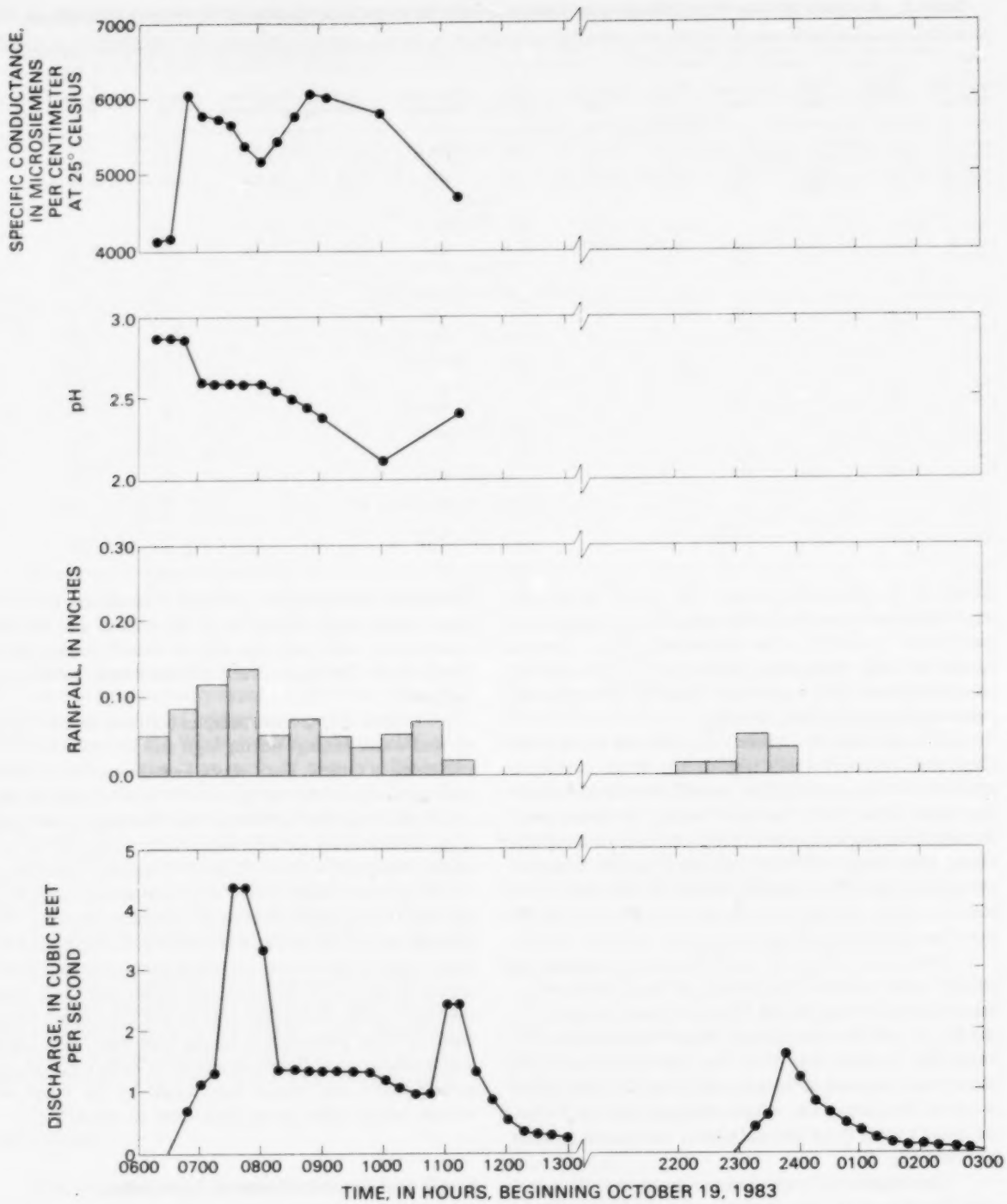


Figure 7. Specific conductance, pH, rainfall, and discharge during storm runoff at North Fork Claybank Creek tributary near Keota (site 8), October 19 and 20, 1983.

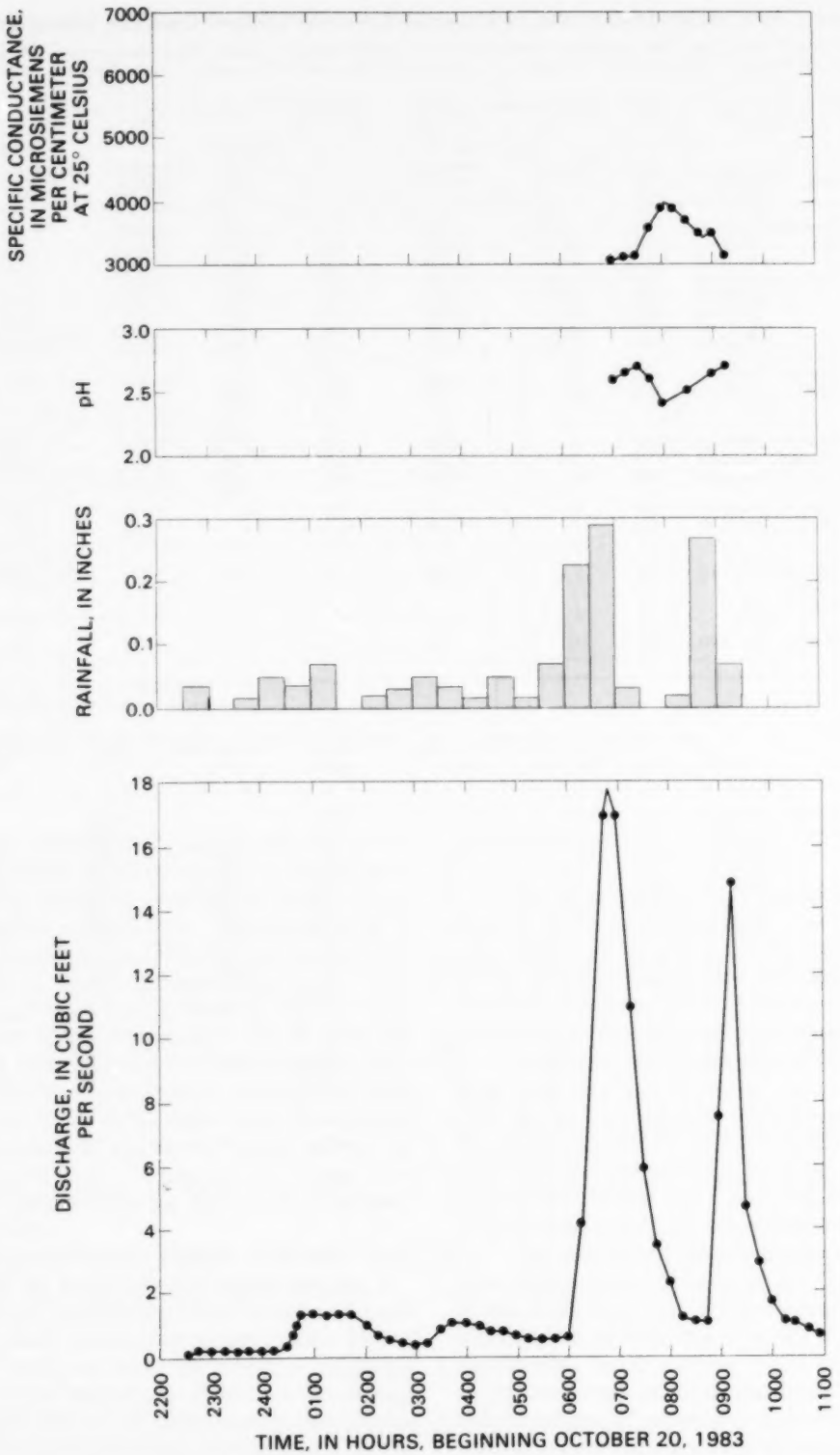


Figure 8. Specific conductance, pH, rainfall, and discharge during storm runoff at North Fork Claybank Creek tributary near Keota (site 8), October 20 and 21, 1983.

Table 3. Analyses of storm runoff samples collected at selected sites in the Claybank Creek and Stinking Creek basins

[Results in milligrams per liter, except as indicated; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25 °Celsius; $CaCO_3$, calcium carbonate; °C, degrees Celsius; mm, millimeters, <, less than; --, no data]

Site number (fig. 1)	Site name	Date	Time	Streamflow (ft^3/s)	Specific conductance (µS/cm)	pH	Acidity (as $CaCO_3$)	Dissolved sulfate	Dissolved solids (residue at 180 °C)	Dissolv alumino
8	North Fork Claybank Creek tributary near Keota[1]	8-30-83	1146	2.2	5,000	2.9	5,610	6,600	9,590	--
		8-30-83	1225	2.2	5,000	2.3	5,560	6,600	9,410	--
		10-19-83	0757	1.4	4,740	2.4	3,820	4,600	6,850	210
		10-19-83	1115	2.2	4,650	2.4	3,080	4,400	--	180
		10-21-83	0658	17.0	3,000	2.6	795	1,400	1,890	41
		10-21-83	0732	6.1	3,100	2.7	944	1,600	2,150	49
		10-21-83	0851	4.0	3,400	2.6	1,240	1,800	2,430	66
		10-21-83	0919	10.0	3,100	2.7	944	1,600	2,150	48
22	North Fork Claybank Creek at beaver bog[1,2]	10-21-83	1015	--	3,200	2.9	--	2,300	3,070	--
		4-12-84	1015	50	305	6.2	<50	--	--	--
23	North Fork Claybank Creek near Thomas Hill Reservoir[1,2]	10-21-83	1040	--	2,100	3.9	--	1,300	1,840	2.
		10-21-83	1215	.6	2,100	3.9	50	1,300	1,860	2.
		4-12-84	1045	50	450	6.0	5.0	--	--	--
36	South Fork Claybank Creek at County Highway C[2]	5-14-81	1845	61	1,270	7.2	--	550	985	--
		10-21-83	1235	--	1,300	6.4	--	--	--	--
42	South Fork Claybank Creek near Thomas Hill Reservoir[2]	10-21-83	1105	1.2	1,800	7.2	50	1,100	1,650	<.
44	Stinking Creek near Callao	10-21-83	(4)	(4)	200	7.3	--	38	132	

Site number (fig. 1)	Site name	Date	Time	Total aluminum	Dissolved copper	Total copper	Dissolved iron	Total iron	Dissolved lead	Tota lea
8	North Fork Claybank Creek tributary near Keota[1]	8-30-83	1146	330	--	0.93	--	1,200	--	<0.0
		8-30-83	1225	--	--	--	--	870	--	--
		10-19-83	0757	240	0.51	.70	660	990	<0.001	<.
		10-19-83	1115	--	.45	--	640	--	<.001	--
		10-21-83	0658	80	.12	.38	120	530	<.003	1.
		10-21-83	0732	68	.14	.25	170	390	<.001	.
		10-21-83	0851	100	.17	.43	220	570	<.001	.
		10-21-83	0919	82	.14	.29	170	520	<.001	.
22	North Fork Claybank Creek at beaver bog[1,2]	10-21-83	1015	--	.075	--	100	--	<.001	-
		4-12-84	1015	8.8	--	.013	--	6.2	--	-
23	North Fork Claybank Creek near Thomas Hill Reservoir[1,2]	10-21-83	1040	--	.005	--	1.5	--	.002	-
		10-21-83	1215	3.0	.005	--	2.1	4.4	.004	-
		4-12-84	1045	3.1	--	.008	--	9.5	--	-
36	South Fork Claybank Creek at County Highway C[2]	5-14-81	1845	--	--	--	.27	3.1	--	-
		10-21-83	1235	--	--	--	--	--	--	-
42	South Fork Claybank Creek near Thomas Hill Reservoir[3]	10-21-83	1105	1.1	.001	.008	.076	3.6	.001	
44	Stinking Creek near Callao	10-21-83	(4)	51	.004	.049	.038	53	.006	

Table 3. Analyses of storm runoff samples collected at selected sites in the Claybank Creek and Stinking Creek basins—*Continued*

Site number (fig. 1)	Site number	Date	Time	Dissolved manganese	Total manganese	Dissolved zinc	Total zinc	Suspended sediment	Suspended sediment finer than 0.062 mm (percent)
8	North Fork Claybank Creek tributary near Keota[1]	8-30-83	1146	--	8.8	--	54.0	14,700	80.8
		8-30-83	1225	--	7.3	--	--	13,600	66.2
		10-19-83	0757	5.1	5.5	37	37	12,700	77.1
		10-19-83	1115	5.2	--	33	--	7,220	80.6
		10-21-83	0658	1.7	1.9	7.8	8.3	19,900	63.8
		10-21-83	0732	1.9	2.0	8.7	8.6	8,340	72.0
		10-21-83	0851	3.1	3.2	11	11	19,300	56.6
		10-21-83	0919	1.7	1.7	8.7	8.5	13,600	73.9
22	North Fork Claybank Creek at beaver bog[1,2]	10-21-83	1015	6.4	--	5.7	--	574	91.6
		4-12-84	1015	--	.51	--	.18	--	--
23	North Fork Claybank Creek near Thomas Hill Reservoir	10-21-83	1040	7.9	--	.77	--	318	92.3
		10-21-83	1215	8.1	7.8	.75	.79	167	68.4
		4-12-84	1045	--	.78	--	.58	--	--
36	South Fork Claybank Creek at County Highway C[1,2]	5-14-81	1045	.80	.88	--	--	15	--
		10-21-83	1235	--	--	--	--	--	--
42	South Fork Claybank Creek near Thomas Hill Reservoir[2]	10-21-83	1105	1.4	1.6	.044	.070	279	86.4
44	Stinking Creek near Callao	10-21-83	(4)	.027	1.5	.12	.24	2,000	97.4

[1]Site received runoff from coal wastes.
[2]Site received runoff from surface-mined areas.
[3]Estimated.
[4]Sample was a composite for the duration of runoff; therefore, these items cannot be determined.

spoil. Shallow impoundments and closed depressions form between these ridges of spoil and capture most runoff and allow it to either evaporate or infiltrate. Consequently, surface runoff from abandoned spoil is markedly decreased and base flows in area streams probably are increased. Deeper pits generally were left along the edge of a spoil area where the last excavation of overburden was not refilled with spoil. These pits generally are filled with water and often are called last-cut lakes or strip pits. These pits usually receive runoff only from small areas, but they usually collect and drain ground water from the unconfined spoil and Pennsylvanian rocks that lie adjacent to them. The quantity of drainage from the strip pits fluctuates with the water levels in the nearby rock and spoil.

Seventeen of the larger strip pits in the study area were surveyed for geometry. The results indicate that these pits contain a deceivingly large volume of water because of a small surface area-to-depth ratio. The 17 pits surveyed contained about 700 acre-ft of water, but they only had a total surface area of 74 acres. The average maximum depth was 14.5 ft. More specific information on these pits is available from the U.S. Geological Survey, Rolla, Mo.

Hydrochemistry

The 17 strip pits surveyed for geometry, plus 1 additional pit, also were surveyed for specific conductance, water temperature, pH, and dissolved oxygen. These values were determined at the sampling sites and were obtained at 10-ft intervals below the water surface with the top measurements taken at a 3-ft depth.

Maximum specific-conductance values were less than 1,000 μS/cm at 25 °C in 8 pits and ranged from 1,000 to 2,500 μS/cm at 25 °C in the remaining 10 pits. The larger specific-conductance values were associated with water that also contained large dissolved-sulfate concentrations. All strip pits, except two that were affected by coal wastes, had pH values near neutral.

Analyses of strip-pit outflows made during base-flow conditions are given in table 6. Strip-pit outflows in the study area that are unaffected by coal wastes generally can be described as having similar alkalinities, considerably larger concentrations of sulfate, slightly larger concentrations of manganese and zinc, and similar concentrations of other metals to those measured in streams unaffected by mining (table 5, site 44).

Although sulfate can be produced from the

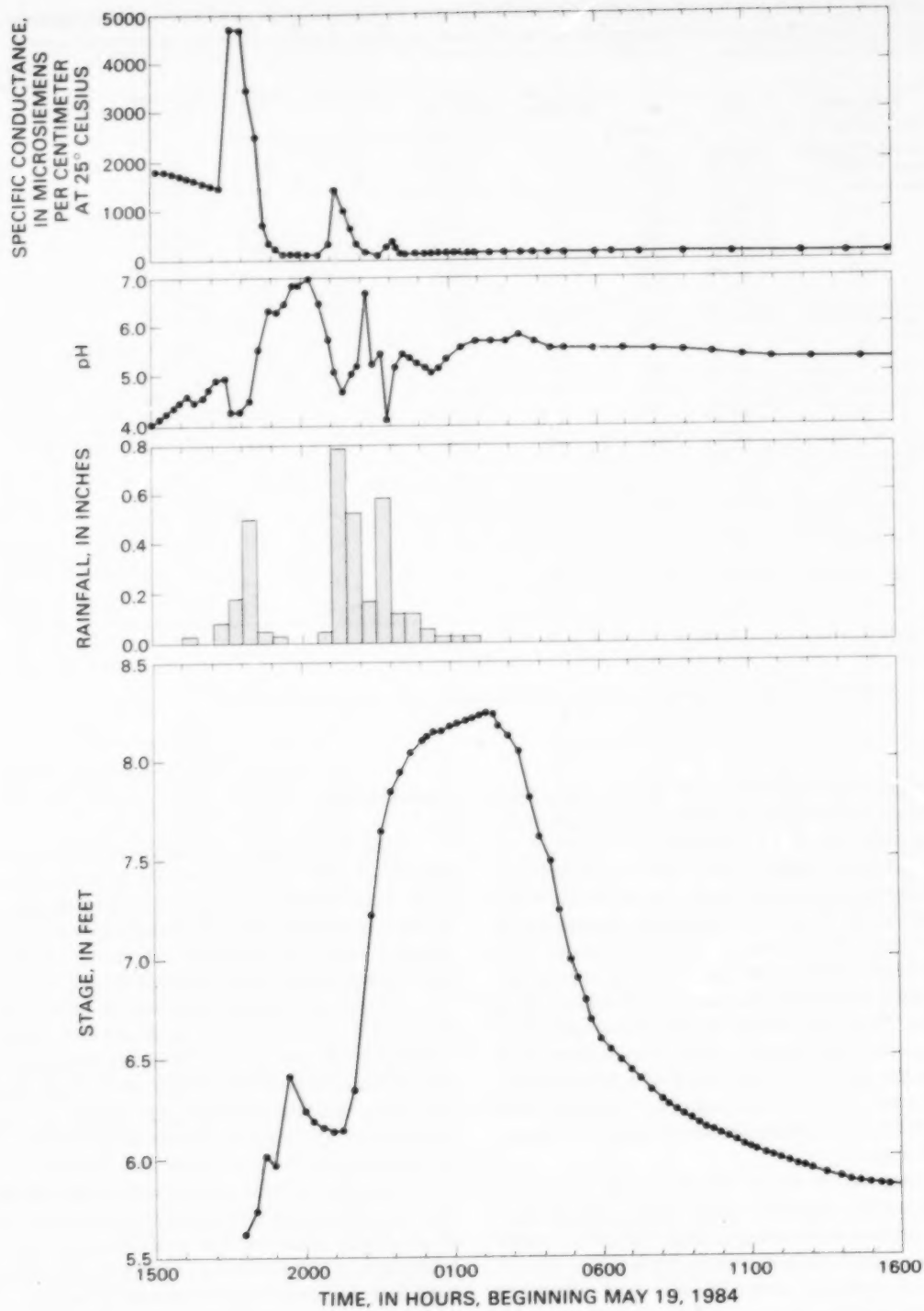


Figure 9. Specific conductance, pH, rainfall, and stage during storm runoff at North Fork Claybank Creek tributary near Keota (site 8), May 19 and 20, 1984.

Table 4. Summary of storm runoff, specific conductance, and suspended-sediment characteristics of selected storms at North Fork Claybank Creek tributary near Keota (site 8) and Stinking Creek near Callao (site 44)

[in., inch; ft^3/s, cubic foot per second; µS/cm, microsiemens per centimeter at 25 °Celsius; mg/L, milligrams per liter; mm, millimeter]

Site number (fig. 1)	Site name	Date	Total storm rainfall (in.)	Runoff volume (millions of cubic feet)	Maximum discharge (ft^3/s)	Mean specific conductance (µS/cm)	Maximum concentration of suspended sediment (mg/L)	Mean storm concentration of suspended sediment (mg/L)	Suspended sediment finer than 0.062 mm (percent)
8	North Fork Claybank Creek tributary near Keota	10-21-83	1.36	0.10	17.0	3,100	19,900	16,000	57
44	Stinking Creek near Callao	10-21-83	1.38	.22	12.0	200	(1)	2,000	97.4
		11-19,20-83	.53	.0675	1.2	300	1,290	348	92
		4-12,13-84	.27	5.6	98	280	956	588	86
		4-21,23-84	1.52	21.7	125	240	2,120	1,100	72

[1]Sample was a composite for the duration of runoff, therefore, this item cannot be determined.

Table 5. Values of properties and concentrations of selected constituents from coal-waste sites and from Stinking Creek (unaffected by mining during base flow

[Concentrations in milligrams per liter, except as indicated. Sources can be located by site number in figure 1. Low base-flow samples were collected September 21-23, 1983, and high base-flow samples were collected April 18-20, 1984. <, less than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent	Base flow regime	Site number[1]					
		3	6	28	32	34	44
Discharge (cubic feet per second)	Low	0	0	<0.01	0.01	0	0.01
	High	.04	.03	.22	.13	<.01	2.3
Specific conductance (microsiemens per centimeter at 25 °Celsius)	Low	--	--	4,100	3,500	2,500	850
	High	1,400	7,500	5,500	1,800	1,950	520
pH	Low	--	--	2.7	2.3	3.2	8.2
	High	3.9	2.4	2.7	2.8	3.7	7.9
Acidity (as $CaCO_3$)	Low	--	--	1,240	695	89	0
	High	233	5,170	1,540	303	45	<5
Alkalinity (as $CaCO_3$)	Low	--	--	0	0	0	260
	High	0	0	0	0	0	126
Dissolved sulfate	Low	--	--	3,200	1,900	1,900	130
	High	840	7,000	3,300	990	1,200	130
Dissolved solids	Low	--	--	4,340	2,670	1,980	429
	High	1,210	10,300	4,710	1,300	1,760	337
Dissolved aluminum	Low	--	--	33	16	4	<.1
	High	41	350	60	8.0	4.3	<.1
Dissolved copper	Low	--	--	.015	.037	.005	.004
	High	.021	.88	.039	.028	.007	.002
Dissolved iron	Low	--	--	340	90	4.9	.016
	High	1.8	1,600	360	74	1.2	.016
Dissolved manganese	Low	--	--	13	4.7	1.9	.004
	High	3.3	12.0	9.9	2.1	1.3	.32
Dissolved zinc	Low	--	--	.15	1.4	.34	.12
	High	23	50	4.3	.70	.30	.018

[1]Site number:
3, Seepage from tailings at Mine 61.
6, Seepage from coal wastes at Keota.
28, Seepage from coal wastes near Binkley.
32, Outflow from acid strip pit near Binkley.
34, Acid strip pit near coal-waste pond near Binkley.
44, Stinking Creek near Callao.

Table 6. Values of properties and concentrations of selected constituents in drainage from strip-mine pits during base flow

[Concentrations in milligrams per liter, except as indicated. Low base-flow samples were collected September 21-23, 1983, and high base-flow samples were collected April 18-20, 1984. Sources can be located by site number in figure 1. <, less than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent	Base flow regime	Site number[1]					
		19	25	26	30	31	37
Discharge (cubic feet per second)	Low	0	0.07	0.05	0	0	0
	High	.83	.14	.58	1.1	.08	.13
Specific conductance (microsiemens per centimeter at 25 °Celsius)	Low	--	1,800	1,200	--	--	--
	High	390	1,010	870	1,520	1,310	2,620
pH	Low	--	7.6	8.1	--	--	--
	High	7.4	7.5	7.2	8.0	7.4	7.6
Acidity (as $CaCO_3$)	Low	--	0	0	--	--	--
	High	<5	<5	<5	<5	5	15
Alkalinity (as $CaCO_3$)	Low	--	72	190	--	--	--
	High	53	66	76	120	147	397
Dissolved sulfate	Low	--	800	430	--	--	--
	High	130	500	380	780	650	1,500
Dissolved solids	Low	--	1,230	760	--	--	--
	High	251	763	638	1,280	1,080	2,390
Dissolved aluminum	Low	--	<.1	<.1	--	--	--
	High	<.1	<.1	<.1	<.1	<.1	<.1
Dissolved copper	Low	--	.002	.001	--	--	--
	High	.002	.001	.001	.001	.001	.001
Dissolved iron	Low	--	.075	.017	--	--	--
	High	.72	.010	.055	.005	.005	.050
Dissolved manganese	Low	--	.30	.94	--	--	--
	High	.44	.87	.57	.33	.33	.50
Dissolved zinc	Low	--	.052	.014	--	--	--
	High	.019	.063	.017	.026	.042	.020

[1]Site number:
19, Outflow from strip pits at County Highway C near Binkley.
25, Outflow from large strip pit near Binkley.
26, Outflow from long strip pit near Binkley.
30, Outflow from strip pit at County Highway T near College Mound.
31, Outflow from two strip pits at County Highway C near College Mound.
37, Outflow from strip pit near College Mound.
[2]This lake received the outflow from site 25 as inflow. During high base flow it received 0.08 cubic foot per second of inflow from unmined areas.

oxidation of iron sulfide in the spoil (eq. 1), some of the sulfate in drainage from spoil may have come from the dissolution of gypsum (calcium sulfate) in spoil rock. Sulfate is abundant in the Bevier-Wheeler coal seam (Wedge and others, 1976). The oxidation of pyrite that produces sulfate also produces significant quantities of iron (eqs. 1 and 4) that would oxidize and precipitate as $Fe(OH)_3$ at the near-neutral pH values measured in spoil drainage (eq. 2). Large deposits of $Fe(OH)_3$ were not observed on the spoil.

Substantial alkalinities in spoil water indicate that enough carbonate materials are present in and around the spoil to combine with most hydrogen ions, (produced by pyrite oxidation) resulting in the formation of bicarbonate (HCO_3).

The slightly larger concentrations of dissolved manganese in strip-pit outflows are persistent at the pH and oxidation states detected in pits and streams in surface-mined areas, but concentrations of other dissolved metals are relatively small because they have minimal solubilities at neutral pH.

EFFECTS OF MINE-RELATED DRAINAGE ON WATER CHEMISTRY OF RECEIVING STREAMS AND THOMAS HILL RESERVOIR

North Fork Claybank Creek Basin

Low Base Flow

Data collected during low base flow in the North Fork Claybank Creek basin are summarized on plate 1.

Additionally, data from the Black Diamond Mine (site 2), which is outside the north boundary of the basin, have been included. These data are presented in table 7 along with a synoptic analysis from the site on Stinking Creek unaffected by mining (site 44) and water-quality standards from the U.S. Environmental Protection Agency and the Missouri Department of Natural Resources for comparison. Various constituent loads in table 7 are presented as a percentage of the constituent load at site 21 (North Fork Claybank Creek below Mine 25) to show the relative contributions of each source of mine-related drainage to North Fork Claybank Creek (calculation shown at bottom of tables). Site 21 was chosen to represent the total load of mine-related drainage in North Fork Claybank Creek because it is downstream from all sources, but upstream from a beaver bog, which had a significant effect on constituent loads in the stream.

Dry bottom material in the North Fork Claybank Creek stream channels upstream from the northwest part of Mine 25 near Keota (site 14) indicated that no flow had occurred for some time, except on the tributary receiving runoff from the coal wastes near Keota where bottom material was damp. Evidently, the coal-waste surface was impermeable enough to produce runoff while the rest of the basin was absorbing rainfall. There was no flow in the coal-waste tributary at the time of sampling,

Table 7. Values of properties, concentrations, and loads of selected constituents during low base flow from sites at the Black Diamond Mine, in the North Fork Claybank Creek basin, and on Stinking Creek

[Concentrations reported in milligrams per liter. Low base-flow samples were collected September 21-23, 1983. Water-quality standards are for protection of aquatic life (U.S. Environmental Protection Agency, 1976), except as noted, and are presented for comparison. Sources can be located by site number in figure 1. --, no data; <, less than; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1]								Water-quality standard
		2	14	17	18	21	22	23	44	
Discharge	cubic feet per second	0.05	0.07	0.07	0.37	0.21	--	0.06	0.01	None
	percentage of discharge at site 21	--	33	33	176	100	--	29	--	--
Specific conductance	microsiemens per centimeter at 25 °Celsius	3,500	3,500	4,300	3,700	3,600	3,800	2,600	850	None
pH		5.9	5.8	2.5	5.8	3.6	2.8	4.1	8.2	6.5 - 9.0
Acidity as $CaCO_3$	concentration	124	50	2,280	64	646	1,090	40	0	None
	percentage of load[2]	--	2.6	117	23	100	--	1.8	--	--
Alkalinity as $CaCO_3$	concentration	240	180	0	300	0	0	0	260	20 (minimum)
	percentage of load[2]	--	--	--	--	100	--	--	--	--
Dissolved sulfate	concentration	--	2,400	3,860	2,400	2,400	2,400	1,600	130	[3]500
	percentage of load[2]	--	33	53	176	100	--	19	--	--
Dissolved solids	concentration	3,650	3,330	4,900	3,420	3,300	3,480	2,340	419	[3]250
	percentage of load[2]	--	34	49	183	100	--	20	--	--
Dissolved aluminum	concentration	<.1	<.1	92	<.1	3.6	26.0	3.4	.1	None
	percentage of load[2]	--	<.9	650	4.9	100	--	27	--	--
Dissolved copper	concentration	<0.001	<0.001	0.21	<0.001	0.01	0.07	0.009	0.004	[4]0.02
	percentage of load[2]	--	--	700	--	100	--	86	--	--
Dissolved iron	concentration	120	77	360	130	47	95	.75	.016	1.0
	percentage of load[2]	--	55	255	487	100	--	.46	--	--
Dissolved manganese	concentration	4.4	4.1	8.8	4.1	6.2	6.3	8.3	.004	[3].050
	percentage of load[2]	--	22	47	117	100	--	36	--	--
Dissolved zinc	concentration	.040	.06	16.0	.04	.71	5.1	.95	.12	[5].1
	percentage of load[2]	--	2.8	752	9.9	100	--	38	--	--

[1]Site number:
2, Discharge from Black Diamond Mine discharge near Bevier.
14, Discharge from northwest part of Mine 25 near Keota.
17, North Fork Claybank Creek below coal-waste tributary.
18, Discharge from southern part of Mine 25 below Keota.
21, North Fork Claybank Creek below Mine 25.
22, North Fork Claybank Creek at beaver bog.
23, North Fork Claybank Creek near Thomas Hill Reservoir.
44, Stinking Creek near Callao.

[2]Loads are expressed as a percentage of the load at site 21 and are calculated as follows:

$$\frac{\text{Concentration at site (x)} \times \text{Discharge at site (x)}}{\text{Concentration at site 21} \times \text{Discharge at site 21}}$$

[3]U.S. Environmental Protection Agency (1976) drinking-water standard.
[4]Missouri Department of Natural Resources (1982) drinking-water standard.
[5]Missouri Department of Natural Resources (1982) protection-of-aquatic-life standard.

but runoff from 0.49 in. of rain 3 days before sampling had left large quantities of fine coal wastes in the bottom of the channel.

The only two sources of water to North Fork Claybank Creek during the sampling period were from Mine 25 at sites 14 and 18. The water chemistry at the two sources was similar, but the discharge at site 18 was more than five times as much as at site 14. Even though the alkalinity of water from both sources was large, the water quickly became acidic when it came in contact with the coal wastes in the creek bottom (table 7, site 21). These coal wastes were the source of many constituents in the water at site 21.

Although the Mine 25 discharge at site 18 was the largest source of iron in the basin, most of this iron had precipitated in the 4,000-ft-long tributary that conveyed the mine drainage to the main stem because of the rapid conversion of the ferrous ion to the nearly insoluble ferric hydroxide. Most of the manganese and sulfate from site 18 was still in solution at site 21, making site 18 the largest source of these constituents to North Fork Claybank Creek during low base flow.

The beaver bog (large area of shallow water created by beaver dams across the creek) in the downstream reaches of North Fork Claybank Creek had a neutralizing effect on water in the stream. Discharge downstream from the bog decreased from 0.21 to 0.06 ft^3/s, but the pH increased from 2.8 to 4.1. The acidity decreased from 1,090 to 40 mg/L and sulfate concentrations also decreased from 2,400 to 1,600 mg/L in the bog. Evidently, the acidic water was mixing with water in storage, which was more alkaline and had less concentrated constituents causing both dilution and neutralization.

If the discharge at site 22 (just upstream from the beaver bog) is assumed to be the same as site 21 (next site upstream from site 22 where the discharge 0.21 ft^3/s), the beaver bog was, at the time of data collection, being loaded with about 2,000 lbs of sulfate, 30 lbs of aluminum, 0.08 lb of copper, 100 lbs of iron, 4 lbs of manganese, and 6 lbs of zinc per day.

The capacity of the beaver bog to reclaim mine-related drainage can be illustrated by estimating the volume of the bog at 100 acre-ft and using a constant sulfate loading of 2,000 lbs per day. Using these figures, it would take 111 days for the bog to increase to a maximum concentration of 2,400 mg/L of sulfate. Actually, it would take much longer because the loading rate would decrease as concentrations of sulfate larger than 1,600 mg/L were discharged from the bog with time.

High Base Flow

Analyses of samples collected from sites unaffected by mining during high base flow are presented in table 8 for comparison with analyses from mine-drainage sources (table 9) and receiving streams (table 10). These sites are all in the North Fork Claybank Creek and Stinking Creek basins, except site 2, which is slightly north of the North Fork Claybank Creek basin boundary. As in table 7, loads are expressed in tables 8–10 as a percentage of the constituent load at site 21. Data collected during the high base-flow sampling are summarized on plate 2.

During the high base-flow sampling, discharge from parts of the North Fork Claybank Creek basin upstream from mine drainage was 1.5 ft^3/s (table 8, site 10). This water had significant neutralizing and diluting effects on mine drainage downstream. The neutralization of acidic water also caused the precipitation of several metals.

The coal wastes near Keota (site 6) were the largest source of acidity to North Fork Claybank Creek at the time of sampling (tables 9 and 10), despite the fact that the flow at this site accounted for only 0.5 percent of the discharge at site 21. These coal wastes also were the largest source of aluminum, copper, and zinc to North Fork Claybank Creek and the second largest source of sulfate, iron, and manganese. The percentages in tables 7–10 that are greater than 100 indicate a large percentage of the metals are being precipitated downstream as the pH is increased by water in receiving streams. By using the percentages of loads in tables 9 and 10 for the coal-waste drainage (site 6) and the receiving tributary just downstream (site 8), it was calculated that 43 percent of the aluminum, 71 percent of the copper, 99 percent of the iron, and 85 percent of the zinc precipitated from solution in the 1,500-ft reach between sampling sites. The actual precipitation rates calculated for this reach were 54 lbs of aluminum, 0.1 lb of copper, 246 lbs of iron, and 9 lbs of zinc per day. The precipitate often was observed at site 8 as a floc suspended in the flow. Sulfate and manganese did not precipitate because of their greater solubilities at neutral pH values. By adding the percentages in table 9 for the five sampled sources of mine drainage in the North Fork Claybank Creek basin, 80 percent of the dissolved sulfate in solution can be accounted for at site 21.

Metals continued to precipitate in the 5,000-ft reach between sites 8 and 17. All the remaining aluminum, more than 58 percent of the remaining copper, and 99 percent of the remaining iron precipitated in this reach. The actual precipitation rates for this reach were 3 lbs of aluminum, 0.007 lb of copper, and 9 lbs of iron per day. This precipitation occurred as metals in the coal-waste drainage continued toward solution equilibrium at a larger pH value.

Drainage from sites 18 (southern part of underground Mine 25 near Keota) and 19 (outflow from strip pits at County Highway C near Bevier) had small concentrations of dissolved aluminum and copper similar

Table 8. Values of properties, concentrations, and loads of selected constituents during high base flow at sites unaffected by mining in the North Fork Claybank Creek and Stinking Creek basins

[Concentrations in milligrams per liter. Sources can be located by site number in figure 1. High base-flow samples were collected April 18-20, 1984. <, less than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1] 9	10	44
Discharge	cubic foot per second	1.0	1.5	2.3
	percentage of discharge at site 21	17	25	--
Specific conductance	microsiemens per centimeter at 25 °Celsius	370	290	520
pH		7.1	7.3	7.9
Acidity as $CaCO_3$	concentration	<5	<5	<5
	percentage of load[2]	--	--	--
Alkalinity as $CaCO_3$	concentration	72	62	126
	percentage of load[2]	29	38	--
Dissolved sulfate	concentration	86	81	130
	percentage of load[2]	2.8	4.0	--
Dissolved solids	concentration	192	187	337
	percentage of load[2]	4.4	6.4	--
Dissolved aluminum	concentration	.1	.1	.1
	percentage of load[2]	--	--	--
Dissolved copper	concentration	.001	.002	.002
	percentage of load[2]	8.3	25	--
Dissolved iron	concentration	.036	.12	.016
	percentage of load[2]	.07	.34	--
Dissolved manganese	concentration	.21	.20	.32
	percentage of load[2]	1.8	2.5	--
Dissolved zinc	concentration	.004	.008	.018
	percentage of load[2]	.21	.62	--

[1]Site number:
9, North Fork Claybank Creek above County Highway C.
10, North Fork Claybank Creek at County Highway C.
21, North Fork Claybank Creek below Mine 25 discharge.
44, Stinking Creek near Callao.

[2]Loads are expressed as a percentage of the load at site 21 and are calculated as follows:

$$\frac{\text{Concentration at site (x)} \times \text{Discharge at site (x)}}{\text{Concentration at site 21} \times \text{Discharge at site 21}}$$

to the unmined sites, and this actually diluted the concentrations of these constituents in North Fork Claybank Creek. However, drainage from site 18 had large concentrations of dissolved sulfate, iron, and manganese and a relatively large discharge of 0.54 ft^3/s (11 percent of the flow at site 21). Consequently, Mine 25 at site 18 constituted the largest source of these three constituents to receiving streams in the basin. However, iron apparently precipitated before reaching the main stem, because concentrations of iron in the receiving stream at site 21 were much smaller than they were upstream from site 18. The rapid precipitation of iron was caused by a sudden, large increase of the oxidation potential of the underground mine water after it was exposed to the atmosphere. Sulfate and manganese, however, did not precipitate and concentrations of these constituents in the

Table 9. Values of properties, concentrations, and loads of selected constituents during high base flow from the Black Diamond Mine and from drainage sources in the North Fork Claybank Creek basin

[Concentrations in milligrams per liter. Sources can be located by site number in figure 1. High base-flow samples were collected April 18-20, 1984. <, less than; >, greater than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1]					
		2	3	6	14	18	19
Discharge	cubic feet per second	0.09	0.04	0.03	0.04	0.54	0.83
	percentage of discharge at site 21	--	.67	.50	.67	9.0	14
Specific conductance	microsiemens per centimeter at 25 °Celsius	3,500	1,400	7,500	3,500	3,400	390
pH		5.7	3.9	2.4	5.7	5.8	7.4
Acidity as $CaCO_3$	concentration	94	233	5,170	25	74	<5
	percentage of load[2]	--	>67	>1,100	>7.0	>290	--
Alkalinity as $CaCO_3$	concentration	203	0	0	26	242	53
	percentage of load[2]	--	0	0	.55	66	22
Dissolved sulfate	concentration	2,400	840	7,000	2,200	2,400	130
	percentage of load[2]	--	1.5	9.5	4.0	59	4.9
Dissolved solids	concentration	3,680	1,210	10,300	3,260	3,330	251
	percentage of load[2]	--	1.4	8.8	3.7	51	6.0
Dissolved aluminum	concentration	.4	41	350	>.1	>.1	>.1
	percentage of load[2]	--	>590	>3,700	--	--	--
Dissolved copper	concentration	.002	.021	.86	.001	.001	.002
	percentage of load[2]	--	28	880	--	--	55
Dissolved iron	concentration	140	1.8	1,600	23	140	0.072
	percentage of load[2]	--	.14	21,000	400	33,000	26
Dissolved manganese	concentration	4.3	4.6	12.0	4.0	4.0	.44
	percentage of load[2]	--	3.3	6.4	2.9	39	6.5
Dissolved zinc	concentration	.16	1.2	50.0	.05	.04	.019
	percentage of load[2]	--	23	704	.94	10	7.5

[1]Site number:
2, Discharge from Black Diamond Mine discharge near bevier.
3, Seepage from tailings at Mine 61.
6, Seepage from coal wastes at Keota.
14, Mine 25 discharge near Keota.
18, Mine 25 discharge below Keota.
19, Outflow from strip pits at Highway C near Bevier.
21, North Fork Claybank Creek below Mine 25.

[2]Loads are expressed as a percentage of the load at site 21 and are calculated as follows:

$$\frac{\text{Concentration at site (x)} \times \text{Discharge at site (x)}}{\text{Concentration at site 21} \times \text{Discharge at site 21}}$$

main stem at site 21 were increased after receiving drainage from Mine 25.

As during low base flow, the beaver bog decreased the effects of mine drainage during high base flow in North Fork Claybank Creek by increasing the pH values and decreasing the concentrations of sulfate, iron, and zinc. These effects, along with smaller alkalinities downstream from the bog, were caused by both dilution of the high base-flow water with runoff stored in the bog and increased residence time in the bog that allowed iron and zinc to precipitate and approach equilibrium. Flow decreased at least 18 percent through the beaver bog.

Storm Runoff and Bottom Material

Analyses of storm runoff from selected locations in the Claybank Creek and Stinking Creek basins are

Table 10. Values of properties, concentrations, and loads of selected constituents during high base flow in receiving streams in the North Fork Claybank Creek basin

[Concentrations in milligrams per liter. Sources can be located by site number in figure 1. High base-flow samples were collected April 18-20, 1984. <, less than; >, greater than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1]						
		4	8	13	17	21	22	23
Discharge	cubic feet per second	0.41	0.66	2.4	3.2	6.0	--	4.9
	percentage of discharge at site 21	6.8	11	40	53	100	--	82
Specific conductance	microsiemens per centimeter at 25 °Celsius	190	970	410	720	970	910	810
pH		7.6	3.0	7.0	5.6	6.0	6.0	6.7
Acidity as $CaCO_3$	concentration	<5	233	<5	15	<5	<5	<5
	percentage of load[2]	--	>528	--	>160	100	--	--
Alkalinity as $CaCO_3$	concentration	24	0	50	12	41	41	24
	percentage of load[2]	4.0	0	49	16	100	--	48
Dissolved sulfate	concentration	58	470	140	360	510	460	400
	percentage of load[2]	.79	13	11	38	100	--	64
Dissolved solids	concentration	125	672	266	536	734	696	596
	percentage of load[2]	1.2	16	14	39	100	--	66
Dissolved aluminum	concentration	.3	19	<.1	<.1	<.1	<.01	<.01
	percentage of load[2]	>20	>2,100	--	--	100	--	--
Dissolved copper	concentration	.003	.045	.004	.004	.002	.001	.004
	percentage of load[2]	10	255	80	107	100	--	163
Dissolved iron	concentration	.13	69	.25	12.0	8.8	5.2	.99
	percentage of load[2]	.10	89	1.1	73	100	--	9.2
Dissolved manganese	concentration	0.14	2.0	0.87	1.7	2.0	1.7	1.6
	percentage of load[2]	.48	11	17	45	100	--	65
Dissolved zinc	concentration	.16	2.9	.042	.62	.32	.29	.21
	percentage of load[2]	3.4	103	5.2	103	100	--	54

[1]Site number:
4, Outflow from slackwasher pond near Keota.
8, North Fork Claybank Creek tributary below coal wastes near Keota.
13, North Fork Claybank Creek near Keota.
17, North Fork Claybank Creek below coal-waste tributary.
21, North Fork Claybank Creek below Mine 25 discharge.
22, North Fork Claybank Creek at beaver bog.
23, North Fork Claybank Creek near Thomas Hill Reservoir.

[2]Loads are expressed as a percentage of the loads at site 21 and are calculated as follows:

$$\frac{\text{Concentration at site (x)} \times \text{Discharge at site (x)}}{\text{Concentration at site 21} \times \text{Discharge at site 21}}$$

shown in table 3. Analyses of samples collected at site 23 near the mouth of North Fork Claybank Creek (fig. 1) during the small storm of October 21, 1983, indicate that the effects of upstream acidic wastes and runoff from the coal wastes at Keota occur downstream from the beaver bog and are received by Thomas Hill Reservoir. However, analyses of samples collected during the larger storm of April 12, 1984, indicated little or no acid runoff. The factor determining the effects of acidic runoff at the mouth of North Fork Claybank Creek appears to be the size of the storm. If the storm is large enough to produce runoff from large parts of the basin, coal-waste materials from Keota and in the streambed are flushed out and diluted by large quantities of runoff from unmined parts of the basin. During smaller, localized storms, coal wastes can produce a disproportionately large percentage of runoff and, together with coal wastes in the streambed, cause increased effects on downstream reaches.

Data indicating the neutralizing effect of the beaver bog on acidic runoff also are in table 3. Runoff from the storm of October 21 was sampled at site 8 (North Fork Claybank Creek tributary near Keota) and upstream and downstream from the beaver bog (sites 22 and 23). The discharge was decreased by the beaver bog, the pH was increased from 2.9 to 3.9, and concentrations of all

dissolved sulfate and all metals, except manganese, were markedly decreased downstream from the beaver bog.

Bottom-material samples were collected at selected sites downstream from mining areas in the Claybank Creek basin and at sites unaffected by mining in the North Fork Claybank Creek, Stinking Creek, and Middle Fork Little Chariton River basins during low base-flow sampling on September 23, 1983. Stream bottoms in North Fork Claybank Creek were coated with coal wastes from Keota to slightly upstream from the beaver bog (fig. 1) at the time of sampling. Analyses of these samples are shown in table 11. Two of these analyses are of samples collected during previous studies made by the U.S. Geological Survey. Samples were analyzed for total sulfur, total sulfide, and several metals, and for coal between 0.062 and 2.0 mm (millimeters) in diameter. Total sulfur and coal were determined to be the only reliable indicators of coal wastes in the stream bottoms. Concentrations of metals in bottom material evidently are significantly affected by precipitation and solution processes. However, coal wastes from Keota (site 6) evidently had been deposited in bottom material downstream to Thomas Hill Reservoir as indicated by the larger concentrations of total sulfur and coal at sites downstream from Keota than at sites unaffected by mining (table 11).

Table 11. Analyses of bottom-material samples collected at selected sites

[Results in micrograms per gram, except as indicated; mm, millimeter; --, no data]

Site number (fig. 1)	Site name	Date	Total sulfur (percent)	Total sulfide (percent)	Aluminum	Copper	Iron	Lead	Manganese	Molybdenum	Zinc	Coal between 0.062 and 2.0 mm in diameter
1	Middle Fork Little Chariton River near Callao	8-20-80	--	--	2,400	8	1,300	30	2,600	--	60	9
5	Gob pile at Keota[1]	9-23-83	6.28	0.46	1,700	13	17,000	20	18	0.9	500	414
6	Fine coal wastes at Keota[1]	9-23-83	2.91	.11	1,400	14	20,000	50	15	10	270	530
8	North Fork Claybank Creek tributary near Keota[1]	9-23-83	1.54	.01	1,400	14	15,000	30	30	1.2	55	670
13	North Fork Claybank near Keota[1]	9-23-83	.01	.01	1,300	4	10,000	30	1,200	.9	23	16
17	North Fork Claybank below Keota[1]	9-23-83	.32	.01	850	4	12,000	10	60	.2	27	33
21	North Fork Claybank below Mine 25 near Keota[1]	9-23-83	.18	.01	820	5	11,000	10	340	.5	36	44
23	North Fork Claybank Creek near Thomas Hill Reservoir[1]	9-23-83	.16	.01	2,000	7	9,000	20	300	.8	75	75
36	South Fork Claybank Creek at Highway C near College Mound[1]	9-05-79 9-23-83	-- 0.19	-- 0.01	1,200 2,100	12 8	38,000 13,000	24 20	650 1,200	-- 0.9	90 70	-- 147
42	South Fork Claybank Creek near Thomas Hill Reservoir[1]	9-23-83	.09	.01	1,200	5	--	10	950	.7	--	20
43	Claybank Creek Arm of Thomas Hill Reservoir near College Mound[1]	8-31-83	.01	.01	3,500	10	6,000	20	370	.4	47	321
44	Stinking Creek near Callao	9-23-83	.01	.01	1,200	5	8,500	40	2,300	.9	18	1.4
46	Stinking Creek Arm of Thomas Hill Reservoir	8-31-83	.04	.01	3,800	11	3,500	20	300	.4	17	[2]0

[1]Sites affected by mining.
[2]Concentration of coal between 0.062 and 2.0 millimeters was assumed to be zero because entire sample passed through a 0.062-mm sieve.

South Fork Claybank Creek Basin

Low base flow

Data collected during low base-flow in South Fork Claybank Creek and Stinking Creek are summarized on plate 1, and detailed data are presented in table 12. South Fork Claybank Creek divides into two major branches upstream from site 36 at County Highway C (fig. 1). These forks will be designated as north branch and south branch in this report.

During the low base-flow sampling, most of the streams in the basin were dry, including the entire south branch. Only two sites in the entire basin had discharges greater than 0.01 ft^3/s. The big strip pit near Binkley (site 25) in the north branch basin was the only significant source of water to the South Fork Claybank Creek basin. The outflow from the pit measured 0.07 ft^3/s, had a neutral pH, had concentrations of sulfate and iron 4 to 7 times larger, and had manganese concentrations 75 times larger than those at site 44 on Stinking Creek, which is unaffected by mining. However, these concentrations were not exceptionally large compared to most coal-mine drainage in the study area.

High Base Flow

Data collected during the high base-flow sampling in South Fork Claybank Creek are summarized on plate 3, and detailed data are presented in tables 13, 14, and 15. Analyses of samples collected from sites draining into the north branch of South Fork Claybank Creek are shown in table 13; analyses of samples collected from south branch sites are shown in table 14; and data for all sites downstream from the confluence of the two

Table 12. Values of properties and concentrations of selected constituents during low base flow from sites in the South Fork Claybank Creek basin and on Stinking Creek

[Concentrations in milligrams per liter. Sources can be located by site number in figure 1. Low base-flow samples were collected September 21-23, 1984. <, less than; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1]						
		25	26	28	32	34	36	44
Discharge	cubic feet per second	0.07	0.05	[2]0	<0.01	0	<0.01	0.01
Specific conductance	microsiemens per centimeter at 25 °Celsius	1,800	1,200	4,100	3,500	2,500	2,600	850
pH		7.6	8.1	2.7	2.3	3.2	3.5	8.2
Acidity as $CaCO_3$	concentration	0	0	1,240	695	89	109	0
Alkalinity as $CaCO_3$	concentration	72	190	0	0	0	0	260
Dissolved sulfate	concentration	800	430	3,200	1,900	1,500	740	130
Dissolved solids	concentration	1,230	760	4,340	2,670	1,980	2,070	429
Dissolved aluminum	concentration	<.1	<.1	33	16	4.0	12	<.1
Dissolved copper	concentration	.002	<.001	.015	.037	.005	.001	.004
Dissolved iron	concentration	.075	.017	340	90	4.9	4.0	.016
Dissolved manganese	concentration	.30	.94	13	4.7	1.9	13	.004
Dissolved zinc	concentration	.052	.014	.15	1.4	.34	.65	.12

[1]Site number:
25, Outflow from big strip pit near Binkley.
26, Outflow from long strip pit near Binkley.
28, Seepage from coal-waste pond near Binkley.
32, Outflow from acid strip pit near Binkley.
34, Strip pit near coal-waste pond near Binkley.
36, South Fork Claybank Creek at County Highway C.
44, Stinking Creek near Callao.
[2]Drainage from base of coal-waste dam did not reach the stream as surface flow.

Table 13. Values of properties, concentrations, and loads of selected constituents during high base flow from sites in the north branch of South Fork Claybank Creek basin

[Concentrations in milligrams per liter. Sources can be located by site number in figure 1. High base-flow samples were collected April 18-20, 1984. <, less than; >, greater than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1]					
		24	25	26	27	28	29
Discharge	cubic feet per second	0.08	0.14	0.58	1.1	0.22	1.4
	percentage of discharge at site 42	2.9	5.0	21	40	7.9	50
Specific conductance	microsiemens per centimeter at 25 °Celsius	475	1,010	870	1,310	5,500	1,800
pH		7.7	7.5	7.2	7.6	2.7	3.5
Acidity as $CaCO_3$	concentration	<5	<5	<5	<5	1,540	164
	percentage of load[2]	--	--	--	--	>2,420	>1,600
Alkalinity as $CaCO_3$	concentration	125	66	76	77	0	0
	percentage of load[2]	5.0	4.6	22	43	0	0
Dissolved sulfate	concentration	120	500	380	680	3,300	1,100
	percentage of load[2]	.43	3.2	10	34	33	70
Dissolved solids	concentration	305	763	638	1,070	4,710	1,530
	percentage of load[2]	.70	3.1	11	34	30	61
Dissolved aluminum	concentration	<.1	<.1	<.1	<.1	60	8.2
	percentage of load[2]	--	--	--	--	>47,000	>41,000
Dissolved copper	concentration	.001	.001	.001	.001	.039	.007
	percentage of load[2]	--	--	--	--	286	--
Dissolved iron	concentration	.015	.010	.055	2.3	360	34
	percentage of load[2]	.52	.061	.14	1,100	34,400	21,000
Dissolved manganese	concentration	0.71	0.87	0.57	3.5	9.9	2.4
	percentage of load[2]	1.0	22	5.9	69	39	60
Dissolved zinc	concentration	.006	.063	.017	.20	4.3	.62
	percentage of load[2]	.23	4.2	4.7	105	450	413

[1]Site number:
24, North branch at South Fork Claybank Creek above mining.
25, Outflow from big strip pit near Binkley.
26, Outflow from long strip pit near Binkley.
27, North branch of South Fork Claybank Creek above coal-waste pond near Binkley.
28, Seepage from coal-waste pond near Binkley.
29, North branch of South Fork Claybank Creek below coal wastes near Binkley.
42, South Fork Claybank Creek near Thomas Hill Reservoir.

[2]Loads are expressed as a percentage of the load at site 42 and are calculated as follows

$$\frac{\text{Concentration at site (x)} \times \text{Discharge at site (x)}}{\text{Concentration at site 42} \times \text{Discharge at site 42}}$$

branches are shown in table 15. These data can be compared with high base-flow analyses from sites unaffected by mining listed in table 9 and site 24 listed in table 13. Site 42 is near the mouth of South Fork Claybank Creek and is downstream from all sources of mine drainage in that basin. The calculated loads from each source and at all sampled sites in the main stem are expressed as a percentage of the constituent loads at site 42 to show the relative contributions from each source (calculation shown at bottom of tables).

The discharge from site 25 (outflow from a strip pit near Binkley) in the north branch basin was typical of drainage from spoil in that it had larger concentrations of dissolved sulfate and manganese than streams unaffected by mining. Drainage from sites 24 (unaffected by mining) and 25 flowed into the strip pit that outflowed at site 26. The discharge increased through this pit from 0.22 to 0.58 ft^3/s. The concentrations of dissolved sulfate and manganese in the outflow were smaller than concentrations of these constituents in the inflow at site 25.

At the time of sampling, the discharge in the north

Table 14. Values of properties, concentrations, and loads of selected constituents during high base flow from sites in the south branch of South Fork Claybank Creek basin

[Concentrations in milligrams per liter. Sources can be located by site number in figure 1. High base-flow samples were collected April 18-20, 1984. <, less than; >, greater than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1]					
		30	31	32	33	34	35
Discharge	cubic feet per second	1.1	0.08	0.13	0.77	>0.01	2.0
	percentage of discharge at site 42	40	2.9	4.6	28	--	71
Specific conductance	microsiemens per centimeter at 25 °Celsius	1,520	1,310	1,800	1,680	1,950	1,400
pH		8.0	7.4	2.8	3.5	3.7	7.3
Acidity as $CaCO_3$	concentration	>5	5	303	65	45	<5
	percentage of load[2]	--	2.9	<280	<360	--	>10
Alkalinity as $CaCO_3$	concentration	120	147	0	0	0	118
	percentage of load[2]	66	5.9	0	0	--	119
Dissolved sulfate	concentration	780	650	990	920	1,200	700
	percentage of load[2]	39	2.4	5.8	32	--	63
Dissolved solids	concentration	1,280	1,080	1,300	1,330	1,760	1,120
	percentage of load[2]	40	2.5	4.8	29	--	64
Dissolved aluminum	concentration	<.1	<.1	8.0	4.1	1.3	.1
	percentage of load[2]	--	--	>370	>1,100	--	--
Dissolved copper	concentration	.001	.001	.028	.018	.007	.002
	percentage of load[2]	--	--	121	462	--	134
Dissolved iron	concentration	.005	.16	74	17	1.2	.39
	percentage of load[2]	2.4	5.6	4,200	5,700	--	339
Dissolved manganese	concentration	0.33	0.75	2.1	2.1	1.3	1.1
	percentage of load[2]	6.5	1.1	4.9	29	--	40
Dissolved zinc	concentration	.026	.042	.70	.53	.30	.093
	percentage of load[2]	14	1.6	43	190	--	89

[1]Site number:
30, Outflow from strip pits at County Highway T near College Mound.
31, Outflow from two strip pits at County Highway C near College Mound.
32, Outflow from acid strip pit near Binkley.
33, Outflow from lake below acid lake near Binkley.
34, Strip pit near coal-waste pond near Binkley.
35, South branch of South Fork Claybank Creek near County Highway C.
42, South Fork Claybank Creek near Thomas Hill Reservoir.

[2]Loads are expressed as a percentage of the total at site 42 and are calculated as follows:

$$\frac{\text{Concentration at site (x)} \times \text{Discharge at site (x)}}{\text{Concentration at site 42} \times \text{Discharge at site 42}}$$

branch of South Fork Claybank Creek increased between sites 26 and 27 from 0.58 to 1.1 ft^3/s. This increase was partly because of drainage from several small deposits that appeared to be coal wastes. However, little change occurred in the pH, alkalinity, or acidity. Additionally, although there were no detectable contributions of aluminum or copper between sites 26 and 27, there were significant increases in sulfate, iron, manganese, and zinc. These small seeps were the largest source of manganese in the South Fork Claybank Creek basin.

Drainage from the base of the coal-waste dam near Binkley (site 28) was 20 percent of the flow in the north branch, and samples were collected immediately upstream (site 27) and downstream (site 29) from the coal-waste drainage. This drainage had the smallest pH, the largest acidity, and largest concentrations of every sampled constituent of any mine-drainage source in the South Fork Claybank Creek basin. It was the largest source of every sampled constituent, except manganese, to receiving streams in the basin. Because of this inflow, the north branch was changed from an alkaline stream to an acidic stream and had a pH value of 3.5. A comparison of the constituent loads at sites 28 and 29 to the most downstream site (site 42) indicates that most metals are

Table 15. Values of properties, concentrations, and loads of selected constituents during high base flow from sites in the downstream part of the South Fork Claybank Creek basin

[Concentrations in milligrams per liter. Sources can be located by site number in figure 1. High base-flow samples were collected April 18-20, 1984. <, less than; >, greater than; --, no data; $CaCO_3$, calcium carbonate]

Property or constituent		Site number[1] 36	37	42
Discharge	cubic feet per second	2.9	0.13	2.8
	percentage of discharge at site 42	104	4.6	100
Specific conductance	microsiemens per centimeter at 25 °Celsius	1,520	2,620	1,480
pH		6.2	7.8	7.1
Acidity as $CaCO_3$	concentration	10	15	<5
	percentage of load[2]	>920	>14	100
Alkalinity as $CaCO_3$	concentration	50	397	71
	percentage of load[2]	72	26	100
Dissolved sulfate	concentration	840	1,500	790
	percentage of load[2]	110	8.8	100
Dissolved solids	concentration	1,240	2,390	1,250
	percentage of load[2]	103	8.9	100
Dissolved aluminum	concentration	.1	.1	.1
	percentage of load[2]	--	--	100
Dissolved copper	concentration	.002	<.001	.001
	percentage of load[2]	--	--	100
Dissolved iron	concentration	21	.050	.083
	percentage of load[2]	26,000	5.0	100
Dissolved manganese	concentration	2.7	0.50	2.0
	percentage of load[2]	140	1.2	100
Dissolved zinc	concentration	.32	.02	.076
	percentage of load[2]	440	1.2	100

[1]Site number:
36, South Fork Claybank Creek at County Highway C.
37, Outflow from strip pit near College Mound.
42, South Fork Claybank Creek near Thomas Hill Reservoir.

[2]Loads are expressed as percentage of the load at site 42 and are calculated as follows:

$$\frac{\text{Concentration at site (x)} \times \text{Discharge at site (x)}}{\text{Concentration at site 42} \times \text{Discharge at site 42}}$$

precipitating in the receiving stream. The concentration and load of sulfate in the north branch approximately doubled from the coal-waste drainage at site 28. The coal-waste drainage accounted for one-third of the total load of sulfate near the mouth of South Fork Claybank Creek (site 42).

The south branch of South Fork Claybank Creek originates in a strip-mined area south of County Highway T (site 30). Drainage from this area, like nearly all strip-pit drainage in the study area, was neutral, had appreciable alkalinity, large concentrations of sulfate, and small concentrations of metals. Because base flows from

the surface-mined areas were larger than base flows from unmined areas, strip-pit outflows helped stabilize the water chemistry in both branches of South Fork Claybank Creek.

Immediately upstream from its confluence with the north branch of South Fork Claybank Creek, the south branch receives drainage from some acidic pits to the east (pl. 3). The easternmost acid strip pit (site 32) discharged 0.13 ft^3/s on the day it was sampled, which was less than 5 percent of the flow at the mouth of South Fork Claybank Creek. Outflow from the lake caused acidification and contamination of an impoundment and a short tributary immediately downstream (site 33). The strip pit at site 32 contained some coal wastes that had caused the lake to have a pH value less than 3.0 and an acidity of 300 mg/L as $CaCO_3$. The outflow from this lake previously had been neutralized with sodium hydroxide, but on the day of sampling the neutralizers were not functioning. Sulfate concentrations were large, but the percentage of the sulfate load contributed to site 42 was only slightly larger than the percentage of discharge contributed to the flow at that site. The small pH value caused large concentrations of most metals; however, the small discharge limited the lake's total contribution of constituents to receiving streams. The large percentages of the metals load at site 42 represented by this lake indicate that metals precipitated downstream. The drainage from site 33 was effectively neutralized soon after it entered the south branch. The sample collected from south branch near its confluence with the north branch indicates alkaline water that had precipitated all the aluminum, 70 percent of the copper, 90 percent of the iron, and 78 percent of zinc from the acidic pit at site 32. This precipitation was facilitated by a swampy area slightly upstream from site 32. Sulfate, however, continued to accumulate in the dissolved load.

South Fork Claybank Creek at County Highway C (site 36) is immediately downstream from the confluence of the north branch, which was still acidic from the coal-waste drainage, and the south branch, which had been effectively neutralized by strip-pit drainage. The results of the sample analysis in table 15 for site 36 indicate that the alkaline water prevailed. However, the alkalinity was significantly decreased, and the pH was 6.2. All metals, except aluminum, had not yet had time to equilibrate to the new pH value and were still in supersaturated solution at site 36. The mixture of waters from the two branches produced a sulfate concentration of 840 mg/L at County Highway C.

The two sites farthest downstream on South Fork Claybank Creek were sites 36 and 42. These sites were 1.6 mi apart and the intervening reach of the creek received mine drainage from sites 37, 38, and 40 (table 1). Sites 38 and 40 were not sampled because of their small discharge, but site 37 had smaller concentrations of every sampled metal than the receiving stream at site 36. However, the dissolved-sulfate concentration from site 37 was almost twice that of the receiving stream. The discharge from site 37 was only 5 percent of that at site 42; therefore, it had little effect on loads or concentrations in the receiving stream.

A beaver bog between sites 36 and 42 affected South Fork Claybank Creek similarly to the beaver bog on North Fork Claybank Creek. Despite some contributions of mine drainage between these sites, the discharge decreased slightly because of evapotranspiration from or storage into the bog. The pH and alkalinity increased slightly, dissolved-sulfate concentrations decreased slightly, and dissolved concentrations of iron and zinc decreased significantly between sites 36 and 42.

Storm Runoff and Bottom Material

Three water samples were collected during periods of storm runoff at two sites (pl. 3, sites 36 and 42) in the South Fork Claybank Creek basin (table 3). Concentrations of most constituents in these samples were similar to or smaller than those in storm runoff from the unmined Stinking Creek basin or in base flows from South Fork Claybank Creek.

Three bottom-material samples were collected at the same sites as the runoff samples in the South Fork Claybank Creek basin (table 11). Bottom material at County Highway C (site 36) contained a large concentration of coal and a large percentage of total sulfur. These values could be caused by several mining activities in the basin, but some small impoundments of coal wastes with breached dams immediately upstream from the coal-waste pond at Binkley probably are causing the larger values.

Appearance of Streams

The most striking effect of mine-related drainage on streams in the Claybank Creek basin is their appearance (fig. 3). The North Fork of Claybank Creek downstream from the coal-waste tributary at Keota to the beaver bog usually was stained a bright orange. At times, South Fork Claybank Creek was orange downstream from the large coal-waste pond near Binkley to the mouth. The largest deposits of the orange iron hydroxides came from the underground mines at sites 2, 14, and 18. At site 14, about 1 acre was covered with an iron deposit as much as 5 ft thick.

During storm runoff, the reach of North Fork Claybank Creek and its tributary downstream from Keota became black from suspended coal wastes. The beaver bog at site 22 was black at the time of sample collection

(table 3), and a resident living near the mouth of the stream reported seeing the water become black during storm runoff at that location sometime prior to this study. These observations indicate coal wastes from Keota reached Thomas Hill Reservoir.

Thomas Hill Reservoir

Water samples from the Claybank Creek (affected by mining) and Stinking Creek (unaffected by mining) arms of Thomas Hill Reservoir (fig. 1, sites 43 and 46) were collected August 31, 1983, during low base flow, so that effects of mine-related drainage on the reservoir could be determined. Analyses of the samples are shown in table 16. Samples were collected by compositing samples collected at equal-width increments from the cross sections at sites 43 and 46. The samples were collected near the end of a dry summer and the lake level was 1.5 ft below the normal pool elevation of 710 ft.

The pH values in table 16 indicate no effects of mine-related drainage. However, concentrations of total iron and aluminum in the water were more than 50 percent larger, and total manganese, lead, and zinc were about 10 percent larger in the Claybank Creek arm than the Stinking Creek arm. Concentrations of dissolved-solids and sulfate were similar. These data indicate that any effects of mine-related drainage on the water in the Thomas Hill Reservoir at the time of sampling were small.

Thirteen analyses made by Hoyer and Jones (1981) from unknown locations in Thomas Hill Reservoir during 1978, 1980, and 1981, indicated a range of pH values from 7.0 to 8.3, alkalinities from 51 to 71 mg/L, and specific-conductance values from 268 to 517 μS/cm at 25 °C. These data do not indicate any major effects of mine-related drainage on the reservoir water chemistry. However, they do not preclude temporary or isolated effects, such as in the Claybank Creek arm after storm runoff.

Samples of bottom material in the Stinking Creek and Claybank Creek arms of Thomas Hill Reservoir (table 11) were collected from the same cross sections and at the same time as the water samples. No significant differences were determined for the percentage of total sulfur or concentrations of metals between the two sites. However, coal particles between 0.062 and 2 mm in bottom material of the Claybank Creek arm had a concentration 321 μg/g, which is 60 percent of the coal

Table 16. Analyses of water samples collected from two arms of the Thomas Hill Reservoir on August 31, 1983

[Results in milligrams per liter, except as indicated; <, less than]

Properties and constituents	Claybank Creek arm (site 43, fig. 1)	Stinking Creek arm (site 46, fig. 1)
Specific conductance (microsiemens per centimeter at 25 °Celsius)	315	320
pH	8.4	8.8
Dissolved sulfate	82	87
Dissolved-solids residue	189	202
Total aluminum	8.9	5.9
Total copper	.01	<.01
Total iron	8.4	5.5
Total lead	.006	.004
Total manganese	.76	.70
Total molybdenum	.002	.002
Total zinc	.07	.05

concentration in the fine coal wastes at Keota. Analysis of coal could not be made on the Stinking Creek sample because the entire sample passed through a 0.062-mm sieve; therefore, concentration of coal in this arm must be small. The coal data indicate that wastes from Keota have reached the Thomas Hill Reservoir. However, it is doubtful that large quantities of coal wastes were passing through the beaver bog in the suspended form during this study.

The effectiveness of the beaver bogs in decreasing the effects of mine drainage has been documented during high base flow, low base flow, and storm runoff in earlier sections of this report. Undoubtedly, the effects of mine drainage on the Claybank Creek arm of Thomas Hill Reservoir would have been significantly larger had the beaver bogs not been present.

SUMMARY AND CONCLUSIONS

Eighteen sources of mine-related drainage were identified in the Claybank Creek study area. Of those, eight were considered large enough to have detectable effects on pH values and sulfate concentrations in receiving streams. However, only three of these sources significantly affected the chemistry of water in receiving streams. These sources were the coal wastes at Keota (site 6), drainage from underground Mine 25 (site 18), and the coal wastes at Binkley (site 28). These sources supplied, by far, the largest percentages of constituent loads at downstream sites in the Claybank Creek basin.

Most of the underground mines in and around the North Fork Claybank Creek basin are hydraulically connected and receive recharge from vertical percolation. About 80 percent of the discharge leaving the underground-mine system appears at the surface at Mine 25 downstream from Keota. Underground-mine water had a pH value of about 5.9, large alkalinities and acidities, dissolved-sulfate concentrations of about 2,400 mg/L, large concentrations of dissolved ferrous iron, and dissolved-manganese concentrations ranging from 4.0 to 5.3 mg/L. These characteristics were caused by abundant sources of carbonate rocks, manganese stability at neutral pH, and little or no dissolved oxygen in the underground mines. When this water came in contact with oxygen in the atmosphere, the dissolved ferrous iron was oxidized and precipitated as ferric hydroxide in large, orange deposits around the discharge site and in the receiving streams.

Seepage and runoff from coal wastes can be characterized as having a pH value of about 2.5. The acidities and concentrations of dissolved sulfate and metals were larger in coal-waste sources than any other type of source in the study area. Suspended-coal wastes caused the suspended-sediment concentrations to be much larger in runoff downstream from Keota (site 8) than those at the Stinking Creek site (site 44), which was unaffected by mining.

Closed depressions between ridges of unreclaimed spoil decreased runoff and increased base flows from strip mines in the study area. Some of the larger, deeper strip pits in these areas commonly were drains for the spoil and outflowed into streams in the study area. Large sulfate concentrations in the strip-pit outflows came from the dissolution of gypsum and oxidation of iron disulfide minerals in the spoil. However, substantial alkalinities indicated that carbonate rocks were present in sufficient quantities, in and under the spoil, to keep the pH value near neutral. The neutral pH limited the concentration of most dissolved metals in strip-mine drainage, although concentrations of dissolved manganese were larger than at background sites. Two acidic pits were located in surface-mined areas, but both were affected by coal wastes.

At low base flow, the only sources of water to North Fork Claybank Creek were two discharge outlets from underground Mine 25. However, coal wastes from Keota in the streambed caused the water from the underground mines to immediately become acidic once the water reached the main stem. The acidic water caused a downstream beaver bog to have a pH of 2.8, a dissolved-sulfate concentration of 2,400 mg/L, and large dissolved-solids concentrations.

During high base flow, drainage from unmined areas moderated the effects of mine drainage in the main stem of North Fork Claybank Creek. However, the coal wastes at Keota caused a receiving tributary (site 8) to have a pH of 3.0, caused dissolved sulfate to increase more than eight times, and caused dissolved-metals concentrations to increase from one to two orders of magnitude. The underground-mine drainage from Mine 25 downstream from Keota also dominated the water quality in a major tributary of North Fork Claybank Creek.

Runoff from the coal wastes at Keota during small storms in North Fork Claybank Creek basin caused the North Fork of Claybank Creek to have pH values between 2.1 and 2.8 and resulted in large concentrations of suspended-coal wastes, dissolved sulfate, and metals. Small storms also left deposits of coal wastes in the streambeds, which affected the water quality of base flows. The larger storms diluted and flushed coal wastes out of the stream channel and minimized the acidification of water in the channel.

In the South Fork Claybank Creek basin, the only source of water during low base-flow sampling was drainage from a big strip pit near Binkley, which had a sulfate concentration of 800 mg/L. During high base flow, drainage from the coal wastes at Binkley and an acidic lake near Binkley dominated the water chemistry

of tributaries to South Fork Claybank Creek. These sites decreased the pH of receiving streams to less than 3.5 and increased the concentrations of most dissolved sulfate and metals several fold. However, the alkalinity of water from some of the strip pits neutralized the acidic water in South Fork Claybank Creek downstream from County Highway C. Concentrations of most constituents in storm-runoff samples were similar to or smaller than those from unmined areas. Bottom material at County Highway C contained a large concentration of coal and a large percentage of total sulfur, probably because of some small coal-waste impoundments with breached dams upstream.

The appearance of streams in the Claybank Creek basin was severely affected by deposits of orange iron hydroxide and at some sources of mine drainage. Underground mines and coal wastes were the primary sources causing the staining and deposits of iron.

Claybank Creek drains into Thomas Hill Reservoir. No appreciable effects of mine-related drainage on water chemistry in Thomas Hill Reservoir were determined at the time of sampling. However, concentrations of coal in the bottom materials of the Claybank Creek arm of the reservoir were 60 percent of those in coal wastes upstream at Keota, indicating the reservoir had received coal wastes before the presence of beaver bogs in the downstream part of North and South Forks of Claybank Creek. If the beaver bogs had not been present during this study, the effects of mine drainage on the Claybank Creek arm of Thomas Hill Reservoir probably would have been greater.

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SUPPLEMENTAL DATA

Table 17. Water-quality data collected by the Missouri Department of Natural Resources during previous studies

[Results in milligrams per liter, except as indicated; µS/cm, microsiemens per centimeter at 25 °Celsius; $CaCO_3$, calcium carbonate; --, no data]

Site number (fig. 1)	Site name	Date	Specific conductance (µS/cm)	pH	Acidity (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	Sulfate	Dissolved solids	Total iron
4	Outflow from slackwasher pond near Keota	9-02-80	--	--	--	--	--	--	0.67
6	Coal wastes at Keota	8-28-80	--	--	--	--	--	--	1.02
		1-19-81	--	2.2	--	--	--	--	7,040
8	North Fork Claybank Creek tributary near Keota	10-12-77	860	2.9	272	0	40	630	--
		12-11-80	--	2.3	--	--	--	--	1,310
		1-19-81	--	2.5	--	--	--	--	783
10	North Fork Claybank Creek at County Highway C near Bevier	6-25-80	--	--	--	--	--	--	6.27
11	North Fork Claybank Creek tributary at County Highway FF near Bevier	6-25-80	--	--	--	--	--	--	1.17
14	Discharge from northwest part of Mine 25 near Keota	2-23-81	--	5.8	--	--	--	--	99
15	North Fork Claybank Creek below Antioch Cemetery near Keota	5-14-63	--	--	--	--	--	--	58
20	North Fork Claybank Creek tributary above Mine 25 discharge	9-02-80	--	5.4	--	--	--	--	60
		1-19-81	--	3.6	--	--	--	--	--
22	North Fork Claybank Creek at beaver bog	9-10-58	--	3.2	--	--	--	--	--
		11-07-62	--	3.4	--	--	--	--	--
		3-14-63	--	2.8	--	--	--	--	--
		5-14-63	--	3.4	--	--	--	--	--
		10-12-77	670	5.5	52	0	208	582	--
		1-03-78	1,200	6.3	60	--	--	--	--
		1-19-81	--	3.0	--	--	--	--	44
23	North Fork Claybank Creek near Thomas Hill Reservoir	8-28-80	--	--	--	--	--	--	2.2
36	South Fork Claybank Creek at County Highway C	11-7-62	--	3.0	--	--	--	--	--
		5-14-63	--	3.0	--	--	--	--	--
		[1]10-12-77	1,580	6.0	24	70	500	1,530	0.89
		1-03-78	440	6.9	0	--	--	--	--
		1-26-81	--	6.0	--	--	--	--	3.2
37	Outflow from strip pit near College Mound	1-26-81	--	6.7	--	--	--	--	.06
39	South Fork Claybank Creek 1 mile upstream from Thomas hill Reservoir	1-26-81	--	6.1	--	--	--	--	3.9
40	South Fork Claybank Creek tributary near Thomas Hill Reservoir	1-26-81	--	6.0	--	--	--	--	.3
42	South Fork Claybank Creek near Thomas Hill Reservoir	9-02-80	--	--	--	--	--	--	1.0

[1]Analysis of this sample also determined the following concentrations, in milligrams per liter: total manganese (2.3), total nickel (0.083), dissolved nickel (0.075), total zinc (0.090), and dissolved zinc (0.079).

Table 18. Water-quality data from samples collected by the U.S. Geological Survey during previous studies

[Results in milligrams per liter, except as indicated; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °Celsius; $CaCO_3$, calcium carbonate; mm, millimeters; --, no data]

Site number (fig. 1)	Site name	Date	Streamflow (ft^3/s)	Specific conductance (µS/cm)	pH	Acidity (as $CaCO_3$)	Dissolved calcium	Dissolved magnesium	Dissolved sodium	Dissolved potassium
1	Middle Fork Little	8-20-80	0.04	243	1.9	0	27	6.1	8.7	6.5
	Chariton River	12-16-80	1.0	363	6.9	0	--	--	--	--
	near Callao	9-17-81	.06	472	8.2	--	--	--	--	--
36	South Fork Claybank	9-05-79	.60	1,530	7.0	15	--	--	--	--
	Creek at County	3-13-80	.01	2,080	7.2	--	--	--	--	--
	Highway C near	12-16-80	.10	1,720	6.4	3	--	--	--	--
	College Mound	5-14-80	61	1,270	7.2	--	--	--	--	--

Site number (fig. 1)	Site name	Date	Bicarbonate	Alkalinity (as $CaCO_3$)	Dissolved sulfate	Dissolved chloride	Dissolved flouride	Dissolved silica	Dissolved solids	Total nitrite and nitrate as nitrogen
1	Middle Fork Little	8-20-80	120	84	23	6.1	0.3	5.9	154	1.2
	Chariton River	12-16-80	--	59	100	--	--	--	--	--
	near Callao	9-17-81	--	180	39	--	--	--	--	--
36	South Fork Claybank	9-05-79	--	90	820	--	--	--	1,920	--
	Creek at County	3-13-80	--	98	1,300	--	--	--	1,980	--
	Highway C near	12-16-80	--	57	900	--	--	--	1,560	--
	College Mound	5-14-80	--	56	590	--	--	--	985	--

Site number (fig. 1)	Site name	Date	Total phosphorus	Total iron	Dissolved iron	Total manganese	Dissolved manganese	Total nickel	Suspended sediment	Suspended sediment finer than 0.062 mm (percent)
1	Middle Fork Little	8-20-80	0.2	4.7	--	0.60	--	0.009	126	100
	Chariton River	12-16-80	--	1.5	0.90	.86	0.24	--	56	62
	near Callao	9-17-81	--	.86	.20	.21	.18	--	2	0
36	South Fork Claybank	9-05-79	--	2.3	.90	2.8	2.6	--	50	94
	Creek at County	3-13-80	--	.92	.06	2.3	2.2	--	121	86
	Highway C near	12-16-80	--	.73	.46	2.2	2.3	--	45	0
	College Mound	5-14-80	--	3.1	.27	.88	.80	--	15	0

Table 19. Statistical summary of analyses of monthly samples collected from October 1981 to September 1982

[Data from Kurt Piepenburg, University of Wisconsin, written commun., 1984. Results in milligrams per liter, except as indicated; µS/cm, microsiemens per centimeter at 25 °Celsius; $CaCO_3$, calcium carbonate; --, no data]

Site number (fig. 1)	Site name	Number of samples	Specific conductance (µS/cm)		pH		Sulfate		Total iron		Total manganese	
			Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
3	Seepage from tailings piles at Mine 61 near Bevier	11	1,630	530	3.7	1.1	1,180	450	5.5	5.9	7.9	2.8
4	Outflow from slackwasher pond near Keota	12	250	180	--	--	63	22	.12	.13	.15	.16
8	North Fork Claybank Creek tributary near Keota	10	1,350	1,130	3.2	.5	950	970	160	200	5.8	7.4
13	North Fork Claybank Creek near Keota	12	740	910	6.3	1.2	190	50	.19	.25	1.3	.67
14	Discharge from northwest part of Mine 25 near Keota	9	2,420	620	5.6	.2	2,300	540	60	25	5.5	1.0
18	Discharge from southern part of Mine 25 near Keota	11	2,040	1,070	6.1	.4	1,600	630	22	13	3.6	2.1
19	Outflow from pits at County Highway C near Binkley	11	560	290	6.3	1.4	160	40	.12	.10	.38	.48
20	North Fork Claybank Creek tributary above Mine 25 discharge	11	730	560	6.1	1.4	510	720	3.5	11	1.3	1.8
22	North Fork Claybank Creek at beaver bog	12	940	490	5.8	.6	620	400	3.3	4.3	2.7	1.6
23	North Fork Claybank Creek near Thomas Hill Reservoir	12	910	530	5.3	1.1	560	270	3.1	6.0	3.1	1.8
36	South Fork Claybank Creek at County Highway C	11	1,280	450	7.0	.5	760	190	.14	.12	2.1	1.4
42	South Fork Claybank Creek near Thomas Hill Reservoir	12	1,110	500	7.1	.5	800	210	.09	.13	1.2	.7
44	Stinking Creek near Callao	11	810	160	7.3	.6	110	53	.2	.2	.2	.2
45	Stinking Creek near Thomas Hill Reservoir	10	390	160	7.2	.6	98	44	.3	.2	.3	.2

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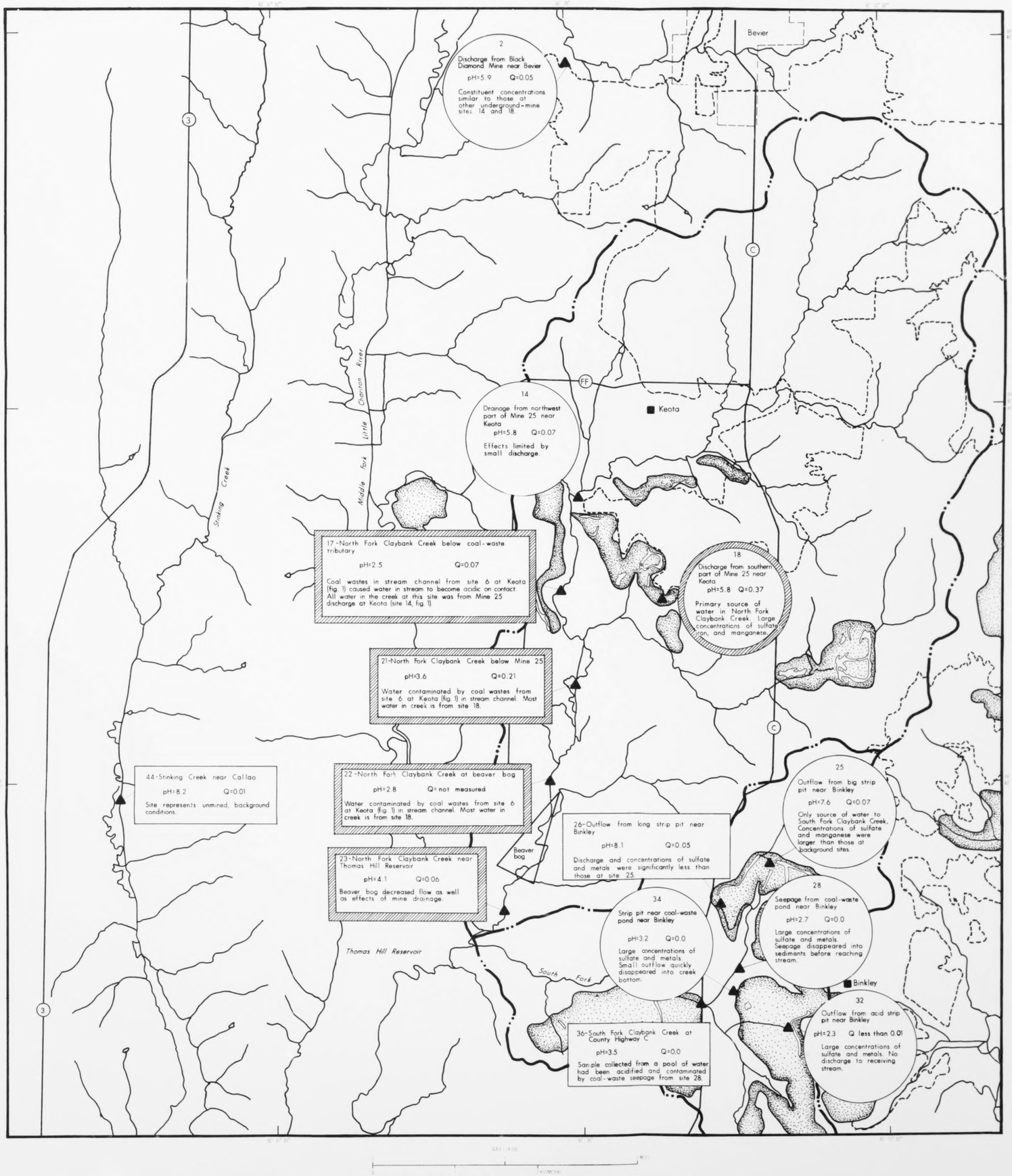
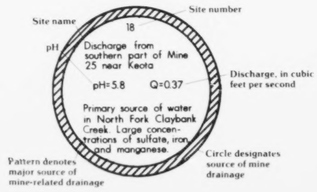
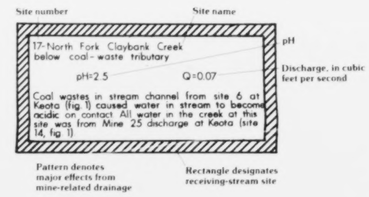
AND
U.S. DEPARTMENT OF THE INTERIOR, OFFICE OF SURFACE MINING RECLAMATION AND ENFORCEMENT

WATER-SUPPLY PAPER 2305
PLATE 1


Bevier
Keota
Binkley
Thomas Hill Reservoir
Beaver bog
Stinking Creek
Middle Fork
Little Chariton River
South Fork
3
C
FF
2
Discharge from Black Diamond Mine near Bevier
pH=5.9 Q=0.05
Constituent concentrations similar to those at other underground-mine sites 14 and 18.
14
Drainage from northwest part of Mine 25 near Keota
pH=5.8 Q=0.07
Effects limited by small discharge.
17-North Fork Claybank Creek below coal-waste tributary
pH=2.5 Q=0.07
Coal wastes in stream channel from site 6 at Keota (fig. 1) caused water in stream to become acidic on contact. All water in the creek at this site was from Mine 25 discharge at Keota (site 14, fig. 1)
18
Discharge from southern part of Mine 25 near Keota
pH=5.8 Q=0.37
Primary source of water in North Fork Claybank Creek. Large concentrations of sulfate, iron, and manganese.
21-North Fork Claybank Creek below Mine 25
pH=3.6 Q=0.21
Water contaminated by coal wastes from site 6 at Keota (fig. 1) in stream channel. Most water in creek is from site 18.
44-Stinking Creek near Callao
pH=8.2 Q=0.01
Site represents unmined, background conditions.
22-North Fork Claybank Creek at beaver bog
pH=2.8 Q=not measured
Water contaminated by coal wastes from site 6 at Keota (fig. 1) in stream channel. Most water in creek is from site 18.
23-North Fork Claybank Creek near Thomas Hill Reservoir
pH=4.1 Q=0.06
Beaver bog decreased flow as well as effects of mine drainage.
26-Outflow from long strip pit near Binkley
pH=8.1 Q=0.05
Discharge and concentrations of sulfate and metals were significantly less than those at site 25.
25
Outflow from big strip pit near Binkley
pH=7.6 Q=0.07
Only source of water to South Fork Claybank Creek. Concentrations of sulfate and manganese were larger than those at background sites.
34
Strip pit near coal-waste pond near Binkley
pH=3.2 Q=0.0
Large concentrations of sulfate and metals. Small outflow quickly disappeared into creek bottom.
28
Seepage from coal-waste pond near Binkley
pH=2.7 Q=0.0
Large concentrations of sulfate and metals. Seepage disappeared into sediments before reaching stream.
32
Outflow from acid strip pit near Binkley
pH=2.3 Q less than 0.01
Large concentrations of sulfate and metals. No discharge to receiving stream.
36-South Fork Claybank Creek at County Highway C
pH=3.5 Q=0.0
Sample collected from a pool of water had been acidified and contaminated by coal-waste seepage from site 28.

EXPLANATION


Site name
Site number
pH
18
Discharge from southern part of Mine 25 near Keota
pH=5.8 Q=0.37
Primary source of water in North Fork Claybank Creek. Large concentrations of sulfate, iron, and manganese.
Discharge, in cubic feet per second
Pattern denotes major source of mine-related drainage
Circle designates source of mine drainage


Site number
Site name
17-North Fork Claybank Creek below coal-waste tributary
pH
pH=2.5 Q=0.07
Discharge, in cubic feet per second
Coal wastes in stream channel from site 6 at Keota (fig 1) caused water in stream to become acidic on contact. All water in the creek at this site was from Mine 25 discharge at Keota (site 14, fig 1)
Pattern denotes major effects from mine-related drainage
Rectangle designates receiving-stream site

Claybank Creek basin boundary

Strip mine

Boundary of mined-out area

MAP SHOWING DATA-COLLECTION SITES AND SUMMARIES OF LOW BASE-FLOW DATA COLLECTED IN THE CLAYBANK CREEK BASIN AND ADJACENT AREAS, NORTH-CENTRAL MISSOURI, SEPTEMBER 21–23, 1983

I19.13:

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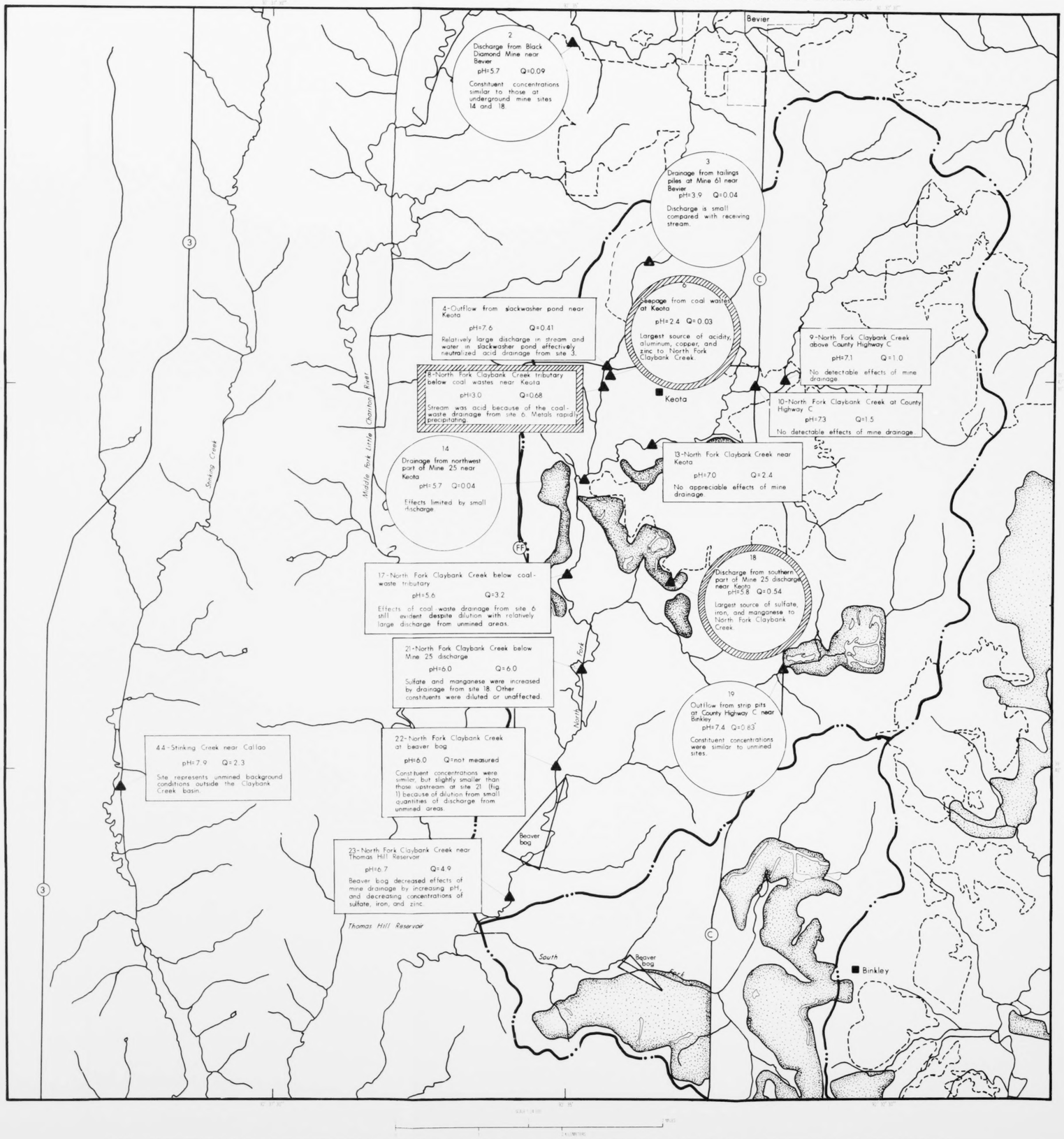
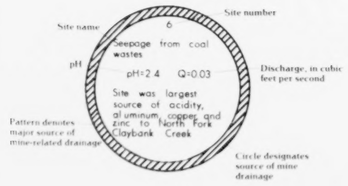
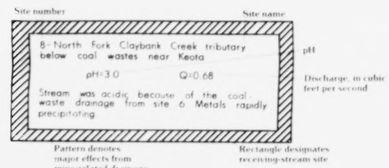
WATER-SUPPLY PAPER 2305
PLATE 2


Bevier
2
Discharge from Black Diamond Mine near Bevier
pH=5.7 Q=0.09
Constituent concentrations similar to those at underground mine sites 14 and 18.
3
Drainage from tailings piles at Mine 61 near Bevier
pH=3.9 Q=0.04
Discharge is small compared with receiving stream.
6
Seepage from coal wastes at Keota
pH=2.4 Q=0.03
Largest source of acidity, aluminum, copper, and zinc to North Fork Claybank Creek.
4-Outflow from slackwasher pond near Keota
pH=7.6 Q=0.41
Relatively large discharge in stream and water in slackwasher pond effectively neutralized acid drainage from site 3.
8-North Fork Claybank Creek tributary below coal wastes near Keota
pH=3.0 Q=0.68
Stream was acid because of the coal-waste drainage from site 6. Metals rapidly precipitating.
9-North Fork Claybank Creek above County Highway C
pH=7.1 Q=1.0
No detectable effects of mine drainage.
10-North Fork Claybank Creek at County Highway C
pH=7.3 Q=1.5
No detectable effects of mine drainage.
Keota
14
Drainage from northwest part of Mine 25 near Keota
pH=5.7 Q=0.04
Effects limited by small discharge.
13-North Fork Claybank Creek near Keota
pH=7.0 Q=2.4
No appreciable effects of mine drainage.
17-North Fork Claybank Creek below coal-waste tributary
pH=5.6 Q=3.2
Effects of coal-waste drainage from site 6 still evident despite dilution with relatively large discharge from unmined areas.
18
Discharge from southern part of Mine 25 discharge near Keota
pH=5.8 Q=0.54
Largest source of sulfate, iron, and manganese to North Fork Claybank Creek.
21-North Fork Claybank Creek below Mine 25 discharge
pH=6.0 Q=6.0
Sulfate and manganese were increased by drainage from site 18. Other constituents were diluted or unaffected.
19
Outflow from strip pits at County Highway C near Binkley
pH=7.4 Q=0.83
Constituent concentrations were similar to unmined sites.
44-Stinking Creek near Catlao
pH=7.9 Q=2.3
Site represents unmined background conditions outside the Claybank Creek basin.
22-North Fork Claybank Creek at beaver bog
pH=6.0 Q=not measured
Constituent concentrations were similar, but slightly smaller than those upstream at site 21 (fig. 1) because of dilution from small quantities of discharge from unmined areas.
23-North Fork Claybank Creek near Thomas Hill Reservoir
pH=6.7 Q=4.9
Beaver bog decreased effects of mine drainage by increasing pH, and decreasing concentrations of sulfate, iron, and zinc.
Thomas Hill Reservoir
Beaver bog
Binkley
Middle Fork Little Chariton River
Sinking Creek
North Fork
South Fork
Beaver bog
3
C
FP

EXPLANATION


Site number
Site name
6
Seepage from coal wastes
pH
pH=2.4 Q=0.03
Discharge, in cubic feet per second
Site was largest source of acidity, aluminum, copper, and zinc to North Fork Claybank Creek
Pattern denotes major source of mine-related drainage
Circle designates source of mine drainage


Site number
Site name
8-North Fork Claybank Creek tributary below coal wastes near Keota
pH
pH=3.0 Q=0.68
Discharge, in cubic feet per second
Stream was acidic because of the coal-waste drainage from site 6. Metals rapidly precipitating.
Pattern denotes major effects from mine-related drainage
Rectangle designates receiving-stream site

Claybank Creek basin boundary

Strip mine

Boundary of mined-out area

MAP SHOWING DATA-COLLECTION SITES AND SUMMARIES OF HIGH BASE-FLOW DATA COLLECTED IN THE NORTH FORK CLAYBANK CREEK BASIN AND ADJACENT AREAS, NORTH-CENTRAL MISSOURI, APRIL 18–20, 1984

I19.13:

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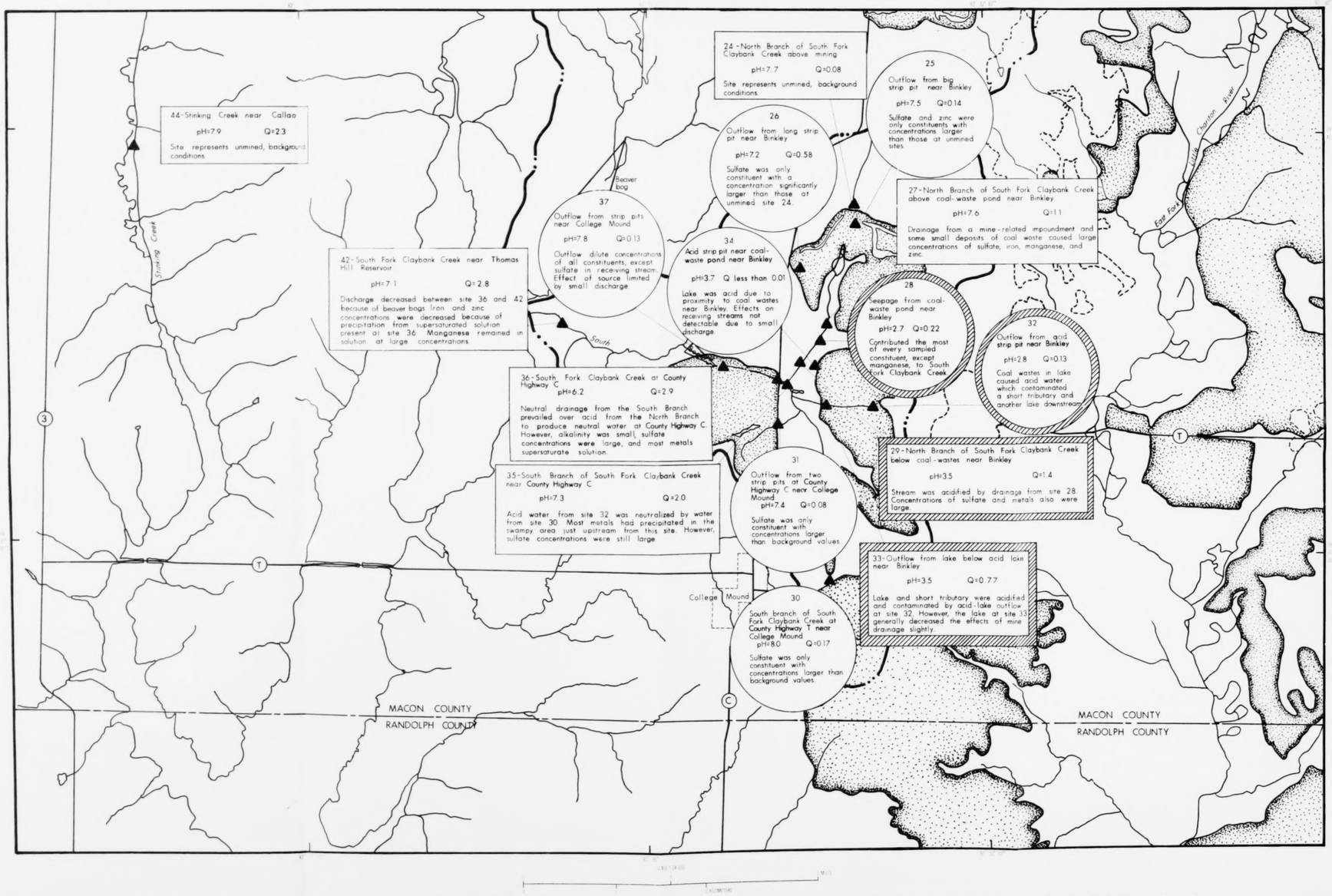
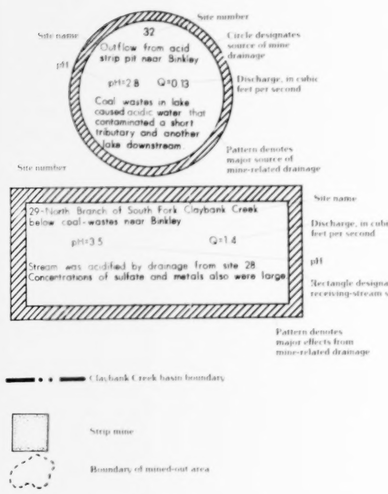
WATER-SUPPLY PAPER 2305
PLATE 3


44-Stinking Creek near Callao
pH=7.9 Q=2.3
Site represents unmined, background conditions.
Stinking Creek
42-South Fork Claybank Creek near Thomas Hill Reservoir
pH=7.1 Q=2.8
Discharge decreased between site 36 and 42 because of beaver bogs. Iron and zinc concentrations were decreased because of precipitation from supersaturated solution present at site 36. Manganese remained in solution at large concentrations.
Beaver bog
37
Outflow from strip pits near College Mound
pH=7.8 Q=0.13
Outflow dilute concentrations of all constituents, except sulfate in receiving stream. Effect of source limited by small discharge.
34
Acid strip pit near coal-waste pond near Binkley
pH=3.7 Q less than 0.01
Lake was acid due to proximity to coal wastes near Binkley. Effects on receiving streams not detectable due to small discharge.
24-North Branch of South Fork Claybank Creek above mining
pH=7.7 Q=0.08
Site represents unmined, background conditions.
26
Outflow from long strip pit near Binkley
pH=7.2 Q=0.58
Sulfate was only constituent with a concentration significantly larger than those at unmined site 24.
25
Outflow from big strip pit near Binkley
pH=7.5 Q=0.14
Sulfate and zinc were only constituents with concentrations larger than those at unmined sites.
27-North Branch of South Fork Claybank Creek above coal-waste pond near Binkley
pH=7.6 Q=1.1
Drainage from a mine-related impoundment and some small deposits of coal waste caused large concentrations of sulfate, iron, manganese, and zinc.
28
Seepage from coal-waste pond near Binkley
pH=2.7 Q=0.22
Contributed the most of every sampled constituent, except manganese, to South Fork Claybank Creek.
32
Outflow from acid strip pit near Binkley
pH=2.8 Q=0.13
Coal wastes in lake caused acid water which contaminated a short tributary and another lake downstream.
36-South Fork Claybank Creek at County Highway C
pH=6.2 Q=2.9
Neutral drainage from the South Branch prevailed over acid from the North Branch to produce neutral water at County Highway C. However, alkalinity was small, sulfate concentrations were large, and most metals supersaturate solution.
35-South Branch of South Fork Claybank Creek near County Highway C
pH=7.3 Q=2.0
Acid water from site 32 was neutralized by water from site 30. Most metals had precipitated in the swampy area just upstream from this site. However, sulfate concentrations were still large.
31
Outflow from two strip pits at County Highway C near College Mound
pH=7.4 Q=0.08
Sulfate was only constituent with concentrations larger than background values.
29-North Branch of South Fork Claybank Creek below coal-wastes near Binkley
pH=3.5 Q=1.4
Stream was acidified by drainage from site 28. Concentrations of sulfate and metals also were large.
33-Outflow from lake below acid lake near Binkley
pH=3.5 Q=0.77
Lake and short tributary were acidified and contaminated by acid-lake outflow at site 32. However, the lake at site 33 generally decreased the effects of mine drainage slightly.
30
South branch of South Fork Claybank Creek at County Highway T near College Mound
pH=8.0 Q=0.17
Sulfate was only constituent with concentrations larger than background values.
College Mound
East Fork Little Chariton River
MACON COUNTY
RANDOLPH COUNTY
MACON COUNTY
RANDOLPH COUNTY
T
C
3

EXPLANATION


Site name
Site number
32
Outflow from acid strip pit near Binkley
pH=2.8 Q=0.13
Coal wastes in lake caused acidic water that contaminated a short tributary and another lake downstream
Circle designates source of mine drainage
Discharge, in cubic feet per second
pH
Pattern denotes major source of mine-related drainage
29-North Branch of South Fork Claybank Creek below coal-wastes near Binkley
pH=3.5 Q=1.4
Stream was acidified by drainage from site 28. Concentrations of sulfate and metals also were large
Rectangle designates receiving-stream site
Pattern denotes major effects from mine-related drainage
Clayback Creek basin boundary
Strip mine
Boundary of mined-out area

MAP SHOWING DATA-COLLECTION SITES AND SUMMARIES OF HIGH BASE-FLOW DATA COLLECTED IN THE SOUTH FORK CLAYBANK CREEK BASIN, NORTH-CENTRAL MISSOURI, APRIL 18–20, 1984

I19.13: